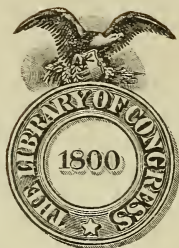


THE
COMBUSTION OF COAL.

W. M. BARR.



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A
PRACTICAL TREATISE

ON THE

COMBUSTION OF COAL,

INCLUDING

DESCRIPTIONS OF VARIOUS MECHANICAL DEVICES FOR THE
ECONOMIC GENERATION OF HEAT BY THE
COMBUSTION OF FUEL,

WHETHER

SOLID, LIQUID OR GASEOUS.

BY

WILLIAM M. BARR.

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1879.

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PREFACE.

This book is intended to present, within a moderate compass, the theory of the combustion of coal, with a view to adapting it to the needs of that large body of men to whom this subject is one of great interest, but who, on account of the abstruse style in which such books are generally written, can not easily obtain the desired information in regard to the chemistry of coal, its combustion, its calorific power, and other matters in this connection, which are not only of interest, but of importance to themselves.

Perhaps no more lucid or accurate presentation of this subject has been written for engineers, than that embodied in Professor Rankine's "Steam Engine and Other Prime Movers," but that work, excellent as it is in itself, is to most persons a book by no means easy to read, or easy to use. It is not that this subject needs to be explained anew, or that there is anything to add to what has already been written, but it is rather to present to the non mathematical reader that which is accepted as high authority among engineers, in a language less difficult to understand.

The absence then, of any purely practical treatise of recent date on this subject, and the belief that such a treatise would supply a want has induced the preparation of this volume. The reader will judge for himself how far this want, if it ever existed, has been met.

This book contains nothing that can be said to be new, but its usefulness need not be impaired on that account if it has the merit of presenting this subject in an accurate and intelligible manner. Much care has been bestowed upon the work to insure its accuracy. The numerous instances in which the writer has converted French *calories* into British *units of heat*, in order to make quotations in the text of any practical value to the reader, has added not a little to the labor of preparation. Wherever quotations have been made from French, German or English writers using the metrical system, the measurements, quantities and temperature have been re-calculated and reduced to American equivalents and Fahrenheit degrees.

In regard to authorities, Professor Rankine's treatise, already referred to, has been consulted at almost every step wherever practicable and largely quoted from. Dr. Percy's treatise on "Fuel," has also been freely used and quoted from; so also, WATTS' *Dictionary of Chemistry*; URE's *Dictionary of Arts, Manufacturers and Mines*; *The Geology of Pennsylvania*, H. D. ROGERS; the Geological Reports of the States of *Ohio, Indiana* and *Illinois*.

Selections have also been made from well known and reliable contributors to the leading scientific journals, including the *Engineer, Engineering, Scientific American*, and others. The writer is also under many personal obligations, and especially so to Professor E. T. Cox, State Geologist, Indiana, not only for valuable contributions of matter, which, from his thorough knowledge of coals, adds much to the value of the book, but for his personal interest and assistance in the preparation of the articles on the chemistry of coal.

Perhaps an apology is needed for the space occupied by the re-print of the report of Dr. Gideon E. Moore on water-gas. To this I can only say, that it was furnished me at my own request, and inserted here on the conviction that a fuel-gas of some sort is one of the pressing needs of the day; and as this report contains so much real information in regard to water-gas not only, but to gaseous fuel in general, I am sure it will amply repay a careful reading, for I believe our present imperfect methods of using crude fuels must, in the larger cities at least, give place sooner or later to the more economical employment of a fuel-gas. The exceeding low cost at which water-gas may be generated, its permanance, certainty, ease of management, cleanliness and economy, are all, certainly, in its favor.

It will be observed there are repetitions here and there through the book; these serve mainly as illustrations in the papers or lectures quoted from, so that it did not seem desirable to break the connection and re-write the sections containing them.

Among the works consulted and quoted from, are the following, arranged in alphabetical order, and numbered. Wherever numbers, enclosed in brackets, occur throughout the text, they refer to the publications corresponding to the numbers as given below.

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ERRATA.

PAGE.	LINE.	CORRECTIONS (IN <i>italics</i>).
16	third from top—	but it also <i>serves</i> to show, etc.
25	tenth from bottom—but,	<i>taken in connection with furnace combustion this pressure is of importance</i> as a mechanical agency, etc.

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CHAPTER I.

PRELIMINARY.

Physical Properties of Coal—Chemical Properties of Bodies—Divisibility of Matter—Molecules—Atoms—Atomic and Molecular Weights—Equivalent Numbers—Symbolic Notation—Energy—Types of Energy—Conversion of Visible into Molecular Energy—Energy of Fuel—The Sun the Source of Energy—The Plants of the Coal Period—The Atmosphere of the Coal Period—The Influence of Light in the Formation of Coal—Dissipation of Energy.

The Physical Properties of Coal include most of the general properties of matter. It belongs to the non-metallic class of bodies, is a solid, varying in structure from hard crystalline, as in the case of pure anthracite, through all gradations to a compact earthy body bearing a close resemblance to wood, both in structure and appearance, and presenting no distinct crystalline fracture when broken. In color it varies from black to dark brown. It is always brittle, and may easily be broken into fragments. Anthracites do not fuse at all in the fire; bituminous coals sometimes fuse, but not without decomposition. In specific gravity it varies from 1.55 to 1.20.

Coal occurs in strata of varying thickness and purity. Carbon and hydrogen are its chief elements, and are those which allow its use with advantage as a source of heat.

The Chemical Properties of a Body are those which relate to its action upon other bodies, and to the permanent changes which it experiences in itself, or which it effects upon them. When a body undergoes chemical change it almost invariably destroys the physical properties held by it previous to this change, but experiment has fully demonstrated that matter is indestructible, so that whatever changes are made in the physical appearance or form of matter by any chemical process, none of it is destroyed.

Divisibility of Matter—A piece of coal may be divided and subdivided until it is reduced to an impalpable powder and still retain all the characteristics of coal, and we might keep on dividing a single grain of this coal—if our senses were acute enough to detect, and we had instruments sufficiently delicate to perform the subdivisions—until at last there would be a piece no longer capable of being subdivided without destroying its composition or nature, there would then be, as a final result, a molecule of coal. If we were to analyze this molecule of coal we would find it to be composed of several substances, such as carbon, hydrogen, oxygen, nitrogen, etc., so that taking a molecule of coal we may reduce it to the elementary substances, which gave it character. These elementary substances are capable of farther subdivision in the same manner, and if any molecule were separately subdivided until it was no longer possible to divide it again, such a piece would be called an atom—not of coal, but of carbon, hydrogen, oxygen, or whatever else it might be. This process would be

partly mechanical and partly chemical. The crushing or reducing to powder would be mechanical; the resolving of the coal into its elements by decomposition is a chemical process. Any compound substance may be resolved into its constituent molecules, and these into atoms, which is the ultimate limit of the divisibility of matter.

Molecules (15)—An atom is a body which can not be cut in two. A molecule is the smallest possible portion of a particular substance. Any substance, simple or compound, has its own molecule. If this molecule be divided, its parts are molecules of a different substance or substances from that of which the whole is a molecule. An atom, if there is such a thing, must be a molecule of an elementary substance.

The old atomic theory, as described by Lucretius and revived in modern times, asserts that the molecules of all bodies are in motion, even when the body itself appears to be at rest. These motions of molecules are, in the case of solid bodies, confined within so narrow a range that even with our best microscopes we can not detect that they alter their places at all.

In liquids and gases, however, the molecules are not confined within any definite limits, but work their way through the whole mass, even when that mass is not disturbed by any visible motion. This process of diffusion, as it is called, which goes on in gases and liquids and even in some solids, can be subjected to experiment and forms one of the most convincing proofs of the motion of molecules. Now, the recent progress of molecular

science began with the study of the mechanical effect of the impact of these moving molecules when they strike against any solid body. Of course these flying molecules must beat against whatever is placed among them, and the constant succession of these strokes is, according to our theory, the sole cause of what is called the pressure of air and other gasses.

We all know that air or any other gas placed in a vessel presses against the sides of the vessel, and against the surface of any body placed within it. On the kinetic theory this pressure is entirely due to the molecules striking against these surfaces, and thereby communicating to them a series of impulses, which follow each other in such rapid succession that they produce an effect which can not be distinguished from that of a continuous pressure. If the velocity of the molecules is given, and the number varied, then since each molecule on an average strikes the side of the vessel the same number of times, and with an impulse of the same magnitude, each will contribute an equal share to the whole pressure.

The pressure in a vessel of a given size is, therefore, proportional to the number of molecules in it, that is to the quantity of gas in it.

This is the complete dynamical explanation of the fact discovered by Robert Boyle, that the pressure of air is proportioned to its density. It shows also that of different portions of gas forced into a vessel, each produces its own part of the pressure independent of the rest, and this whether these portions be of the same gas or not.

Atomic and Molecular Weights—“Equivalent numbers” are often used to express either atomic or molecular weights, and not unfrequently both. Confusion arises in not stating in precise terms which of the two is meant. By referring to one book we find, $H=1$, $C=6$, $O=8$ and $S=16$, etc. By referring to another book we find, $H=1$, $C=12$, $O=16$ and $S=32$, etc. The law of definite proportion assumes that atoms have definite weight; that an atom is a definite and fixed quantity; that atoms of the same substance are of the same size and weight. The confusion arises not that matter has changed, or that the law of proportion has changed, but the nomenclature of the new chemistry is different from the old in the introduction of the word molecule as a substitute for the word atom as it was generally used, and though still retaining it, gives it a specific meaning which is not synonymous or equivalent to the word molecule.

This word molecule means simply a small mass of matter or the smallest portion of a particular substance; an atom means indivisible.

Hydrogen being the lightest known substance, has, by general consent, been made the unit of comparison. It is to be supposed, to begin with, that a molecule of hydrogen consists of two atoms; hence, if the atomic weight of hydrogen is to be taken as 1, the molecular weight is 2. (7). In order to ascertain the molecular weights of other substances—that is to say, the relative weights of their molecules referred to that of hydrogen—it is merely necessary to determine their densities

referred to hydrogen as unity, and then multiply their densities by 2.

When, however, the molecular weights of the elements are compared with their atomic weights it is found they do not always, as in the case of hydrogen, double their atomic weights; hence it is inferred that the molecules of elements do not all contain two atoms. In a few cases the atomic weights and the molecular weights agree, which necessitates the conclusion that the molecules are monatomic or consist of a single atom; in a few other cases the molecular weight is either four or six times the atomic weight, and the molecules are therefore regarded as tetratomic or hexatomic; that is, containing four or six atoms.

The following table gives the molecular weight of the constituents of coal as ordinarily determined by analysis, adding phosphorus which occurs occasionally, but more particularly, to exhibit its molecular as compared with the atomic weight, illustrating what was said in the preceding paragraph:

TABLE I—MOLECULAR WEIGHTS.

NAMES.	SYMBOL.	ATOMIC WEIGHT.	MOLECULAR WEIGHT.	NUMBER OF ATOMS IN A MOLECULE.
Hydrogen.....	H	1	2	2
Carbon.....	C	12	24	2
Nitrogen.....	N	14	28	2
Oxygen.....	O	16	32	2
Phosphorus.....	P	31	124	4
Sulphur.....	S	32	{ 64 192	2 6

It will be seen that two numbers are given for sulphur. This is because at temperatures above 800° C. (1472° Fahr.) the density of sulphur vapor is such as to indicate that the sulphur molecule consists of two atoms, whereas its density at about 500° C. (932° Fahr.) is three times as great, and, consequently, it is said to be supposed that the molecules are hexatomic or contain six atoms.

Table II contains a list of elements found in coal by elementary analysis.

TABLE II.

NAME.	SYMBOL.	ATOMIC WEIGHT.
Aluminum.....	Al.	27.5
Calcium.....	Ca.	40.
Carbon.....	C.	12
Hydrogen.....	H.	1
Iron.....	Fe.	56
Magnesium.....	Mg.	24
Nitrogen.....	N.	14
Oxygen.....	O.	16
Phosphorus.....	P.	31
Potassium.....	K.	39
Silicon.....	Si.	28
Sulphur.....	S.	32

The column of atomic weights in this table means that one atom of carbon is twelve times as heavy as hydrogen, oxygen sixteen times as heavy, nitrogen fourteen times as heavy, etc.

A distinction must be made between atomic weights and equivalent numbers. They do not mean the same thing. The equivalent or combining proportion is an experimental constant which is independent of theoretical considerations; (17) but the relative atomic weight is necessarily a matter of inference, and may be a number, often a multiple of the equivalent, and selected by the chemist from theoretical considerations, based partly upon the law of gaseous volumes, partly on chemical grounds, partly on the phenomena of specific heat.

The law of gaseous volumes, as laid down by Avogadro, means that equal volumes of all gasses under the same conditions have the same number of molecules(3). Then, since a given volume of oxygen gas weighs sixteen times as much as the same volume of hydrogen gas the molecule of oxygen must weigh sixteen times as much as the molecule of hydrogen; and, if we assumed the hydrogen molecule as the unit of molecular weight, the molecule of oxygen would weigh sixteen of these units, hence the atomic weight of oxygen would be sixteen.

Symbolic Notation—In the preceding tables, the letters H for hydrogen, C for carbon, etc., appear; this is for two reasons:

1. It belongs to an agreed symbolic language by which elements may be recognized at sight by the use of the first letter, as far as practicable, of its Latin name.

2. It facilitates the representation of chemical changes, by which reactions of a complicated character may be understood at a glance.

These symbols are not simply abbreviations of the names of the elements, but represent the atomic weights of the elements for which they stand; thus, C represents carbon not only, but its atomic weight as well, and may be expressed as follows: Carbon = C = 12. This is not an exact expression, but serves to show the value of C as a symbol, representing the name of the element carbon, and its atomic weight, 12. Whenever a symbol is used singly, it means an atom of the element represented; C represents carbon not only, but one atom of carbon. A combination of elements is represented by a combination of symbols placed side by side; thus—one atom of carbon and one atom of oxygen would be expressed as CO, and by this we mean carbonic oxide, a very common product of the combustion of coal.

We also understand by this, that one atom of carbon and one atom of oxygen combine to form, not one atom, but one molecule, of carbonic oxide.

Suppose we added to the molecule of carbonic oxide (CO), another atom of oxygen, or $\text{CO} + \text{O}$, we understand the compound to consist of one atom of carbon and two atoms of oxygen, and, as a less complicated expression the formula CO_2 is used. This is the symbolic expression of one molecule of carbonic acid, the product of the complete combustion of carbon and oxygen. The atomic value of each element in a com-

pound remains unchanged, and the aggregate weight of the atoms forms the molecular weight of the compound, whatever it may be.

$$\begin{array}{rcl}
 \text{One molecule of carbonic acid} & = & \text{one atom carbon } C \times 12 = 12 \\
 & & \text{two atoms of oxygen } O_2 \times 16 = 32 \\
 & & \hline
 & & CO_2 = 44
 \end{array}$$

the weight of one molecule of carbonic acid.

Whenever two or more atoms of a body enter into the formation of a molecule, it is most conveniently expressed by writing a small figure to the right of the letter and below the line, whenever practicable, or making it smaller than the symbol, when not so; C_3 indicates three atoms of carbon, $H_8 = 8$ atoms of hydrogen; $C_3 H_8$ is the formula for one of the products of coal occurring in the Marsh gas series, and known as prophyl hydride, and this formula is the expression of one molecule. $2 C_3 H_8$ would be the expression representing two molecules, and so on.

Secondary compounds, such as salts, are expressed in an analogous way, the metal being usually placed first, $Ca CO_3$ representing one molecule of carbonate of calcium—calcium being the metallic base (17).

When a comma is used to separate two compounds, a more intimate union is supposed than when the sign + is used.

Suppose in the analysis of the product of the combustion of coal we have in 100 parts the formula $87 CO_2 + 13 H_2 O$ as representing the constituents of the sample analyzed. It means that 87 per cent. is carbonic

acid, and 13 per cent. water or vapor, as the latter will probably be condensed and disappear, while the former may still retain its permanency as a gas; the sign + is interposed to separate or distinguish the one from the other.

A very little practice will enable one to determine at sight the elements in any formulated compound, and give to each its proper atomic weight.

Energy is the power of doing work. By work is meant overcoming resistance. If a body weighing one pound be lifted one foot high against the action of gravity, we have then the unit of work called a *foot-pound*. Thirty-three thousand pounds raised one foot high in a minute is called a *horse-power*. Five hundred and fifty pounds raised one foot high in a second amounts to the same thing, because: $550 \text{ lbs.} \times 60 \text{ sec.} = 33,000 \text{ lbs. one foot high in 60 seconds or 1 minute.}$

The unit of work as laid down in most foreign scientific books is the *kilogrammetre*; this represents the work done in raising one kilogramme one metre high against the force of gravity at the earth's surface. This unit of work is rarely used in this country, and, unless otherwise stated when used, we shall employ the foot-pound as the unit of work in this book.

Types of Energy—Energy is of two types, known as kinetic and potential.

Kinetic energy is the energy due to motion.

Potential energy is the energy due to position.

Let us suppose a brick house in course of erection, and attained a height of, say, twenty feet above the ground; a man standing on the ground may throw a brick to another man on the scaffold, at that height. If, instead of using his muscular strength to throw the brick to that height, he simply "let go" of the brick, it would, in obedience to the law of gravitation, fall to the ground; but, instead, he gives the brick a toss, and it ascends against the attraction of the earth to something more than the height of the scaffold, ceases to rise, and begins to fall when the man above catches it, and places it beside him on the scaffold. We have in this simple illustration examples of the two types of energy. The flight of the brick upwards is due to the impulse it received at the hands of the man on the ground—it is a consequence of muscular effort—it is an example of work done, because, resistance has been overcome. The brick in its flight has a property which it did not have on the ground. That property is energy—energy due to motion, or kinetic energy. The amount of energy or capacity it has for doing work is a certain quantity, and is equal to the weight of the brick multiplied into the height it ascended above the man's hands before it began its downward flight.

The brick on the scaffold is at a state of rest, but it has not lost its energy. It is, however, of a different type from that in the preceding paragraph. The brick on the scaffold, though at rest, has a capacity for doing work simply on account of its elevation.

This is called the energy of position or potential energy. Suppose the brick to be pushed over the edge of the scaffold ; it will fall by virtue of gravitation, and when it reaches the height of the man's hands, from which the brick was projected upward, the two energies will exactly equal each other, except in so far as it is modified by the resistance of the air. This, however, gives no exception to the general truth of the principle of conservation of energy, because any energy lost by the brick is communicated without loss of quantity to the surrounding air.

These two kinds of energy, energy of motion and energy of position, are being continually changed one into the other. An illustration of this conversion of one form of energy to another is seen in a head of water employed to turn a water wheel. The water in the dam possesses energy on account of its height above the wheel. The weight of this water impinging against the arms of the wheel imparts motion to it, and, we have in the wheel a store of energy due to motion, which, by suitable connections, is capable of doing work. This is an example of the transmutation of energy; that is, the changing of one kind of energy into another. There are many varieties of visible energy, but there is energy which is invisible, and, the one may be converted into the other. The most common illustration of this is the conversion of work into heat.

Conversion of Visible into Molecular or Invisible Energy
—This occurs when motion is arrested, whether by percussion or by friction. It is the conversion of work into

heat. If a lead bullet be fired against an iron target its *motion* is destroyed by impact, but not so its energy. The ball will have performed work in the act of flattening itself, and in rebounding from the target, but in addition to this it will be found to be quite hot. If we had an instrument delicate enough to measure the temperature of the target after the ball had come in contact with it, we would find it to be higher than it was before the ball struck it. If we could gather together the friction of the ball in the gun, the resistance of the ball in the air, the work done in overcoming gravitation, the work done in the act of flattening the ball, the work done in the rebound, the work done in producing the tremor of the target, together with the heat generated by impact, we would then have an amount of energy exactly equal to the energy imparted to the ball by the powder at the moment of explosion. A conversion of visible or actual energy into heat.

If two pieces of dry wood are rubbed together with considerable pressure they get quite hot, and it is possible, if this rubbing were continued long enough, they would in time "take fire" and burn. The ordinary explanation of this is, that heat has been generated by friction. This is quite true, but it is also to be explained on the theory that work has been converted into heat.

The great characteristic of energy is, that it may be transformed or transmuted from one kind of energy into another kind of energy, but through all its transformations the quantity present always remains the same; though known by different names, we ought not to for-

get that energy is always the same thing, and the various names given to energy are simply those of convenience in classification.

ENERGY OF FUEL—The principal fuel in all civilized countries is coal. It contains, within an unattractive exterior, a store of energy almost incredible. Having an area in this country alone, of nearly two hundred thousand square miles of coal formation, we may form some idea of this vast force now latent, but ready to obey the law of its nature, demanding only that the conditions be favorable for the conversion of its constituent elements, through the agency of a chemical union with oxygen, in order to convert this passive and inert mass of carbonaceous matter into heat, a force, capable of performing greater or less work through the medium of heat engines, as the conditions are more or less favorable for economic conversion.

The greater part of the coal formation in this country is bituminous; it contains less carbon than anthracite, but its heating power, pound for pound, is not much less if pure, and free from earthy matter. The volatile portions being rich in hydro-carbon, giving off great heat if combustion is perfect.

The energy of fuel or its power to do work may easily be computed by assuming a value of 14,500 heat units in one pound of coal, this multiplied by 772, the thermal unit known as Joule's equivalent would give: $14,500 \times 772 = 11,194,000$ pounds raised one foot high in one minute, representing the potential energy of one pound of coal.

This of course represents the utmost limit of work in one pound of coal, and which never can be arrived at in practice, but it also seems to show the vast store of energy in the coal, and the latent force capable of ministering to our needs, by the simplest mechanism.

The Sun the Source of Energy—If we would know the beginnings of coal formation we must go back through the ages to the period known as the carboniferous age. Coal is believed to be vegetable matter, which has undergone both chemical and mechanical changes during the ages in which it has been buried under the strata of the earth's crust. The flora of that period was rank in the extreme; fortunately, specimens occur by which a "restoration" of the characteristic plants which play so important a part in coal formation having been carefully removed, and serve to show not only the structure of the plant, interesting in itself, but gives us an idea from our knowledge of tropical vegetation how intense the heat, and how humid the atmosphere, laden with carbonic acid, stimulating all vegetation to colossal growth.

Wood exposed to the oxygen of the atmosphere is slowly but entirely rotted and destroyed; even if buried, the oxygen having access through the particles of sand will in time produce the same result; but if the action of the oxygen of the atmosphere is nearly or entirely prevented, the woody matter is slowly burned into coal. This proceeding does not come to its end without a great many changes. One of these modifications is the transformation of the woody matter into a soft black

mud; the ever-increasing strata above this formation varying from hundreds to thousands of feet crushes together the cell walls of the vegetable matter, producing not only a flattening but a hardening effect by reason of this immense pressure, the intensity of which may be imagined if we suppose earth, rock, etc. to weigh about eighty pounds per cubic foot on an average.

The most conspicuous and abundant of the trees of the coal period was the *sigillaria* or seal tree. They grew to a height from thirty to sixty feet, though they are said to have attained a height of seventy feet and a diameter of five feet. They, more than any other genus of plants, contributed to the coal formation. Some twenty-eight varieties of this tree are described in the *Geology of Pennsylvania*—Rogers—vol. ii, p. 871–3.

“These trees (6) present tall, pillar-like trunks, and marked by rows of scars left by the fallen leaves. They are sometimes branchless, or divide at the top into a few thick limbs, covered with long, rigid grass-like foliage. On their branches they bear long, slender spikes of fruit, and we may conjecture that quantities of nut-like seeds scattered over the ground around their trunks are their produce. If we approach one of these trees closely, more especially a young specimen not yet furrowed by age, we are amazed to observe the accurate regularity and curious forms of the leaf-scars, and the regular ribbing so very different from that of our ordinary forest trees. If we cut into its stem, we are still further astonished at its singular structure. Exter-

nally it has a firm and hard rind; within this is a great thickness of soft cellular inner bark, traversed by large bundles of tough fibres. In the center is a core or axis of woody matter, very slender in proportion to the thickness of the trunk, and still further reduced in strength by a large cellular pith. Thus a great stem four or five feet in diameter is little else than a mass of cellular tissue, altogether unfit to form a mast or beam, but excellently adapted, when flattened and carbonized, to blaze upon our winter hearth as a flake of coal. The roots of these trees were perhaps more singular than their stems; spreading widely in the soft soil by regular bifurcation, they ran out in long, snake-like cords, studded all over with thick cylindrical rootlets, which spread from them in every direction. They resembled in form, and probably in function, those cable-like root-stocks of the pond-lilies, which run through the slime of lakes, but the structure of the rootlets was precisely that of those of some modern Cycads. It was long before these singular roots were known to belong to a tree. They were supposed to be branches of some creeping aquatic plant, and botanists objected to the idea of their being roots; but at length their connection with sigillaria was observed simultaneously by Mr. Binney, in Lancashire, and by Mr. Richard Brown, in Cape Breton, and it has been confirmed by many subsequently observed facts. This connection, when once established, further explained the reason of the almost universal occurrence of stigmaria, as these roots were called, under the coal beds; while trunks of the same plants were the most abundant fossils

of their partings and roofs. The growth of successive generations of sigillaria was, in fact, found to be the principal cause of the accumulation of a bed of coal."

We have not the space to devote to the numerous other plants found in coal formation, nor to the successive cosmical changes which for ages have buried these plants so far beneath the present surface of the earth, but wish to show that the sun which gave to these plants both light and heat is really the source from whence all this energy is derived.

Prof. Tyndall, in his "Heat as a mode of motion" quotes (section 707) from Sir John Herschel,* "The sun's rays are the ultimate source of almost every motion which takes place on the surface of the earth. By its heat are produced all winds, and those disturbances in the electric equilibrium of the atmosphere which give rise to the phenomena of lightning, and probably also to terrestrial magnetism and the aurora. By their vivifying action, vegetables are enabled to draw support from inorganic matter, and become in their turn the support of animals and man, and the source of those great deposits of dynamical efficiency which are laid up for human use in our coal-strata. By them the waters of the sea are made to circulate in vapor through the air, and irrigate the land, producing springs and rivers. By them are produced all disturbances of the chemical equilibrium of the elements of nature, which, by a series of compositions and decompositions, give rise to new products and originate a transfer of materials. Even the slow gradation of the

* Outlines of Astronomy, 1833.

solid constituents of the surface, in which its chief geological change consists, is almost entirely due, on the one hand, to the abrasion of wind or rain and the alternation of heat and frost; on the other, to the continual beating of sea-waves agitated by winds, the results of solar radiation."

In section 710 Prof. Tyndall says: "In the building of plants, carbonic acid is the material from which the carbon of the plants is derived, while water is the substance from which it obtains its hydrogen. The solar beam winds up the weight; it is the agent which severs the atoms, setting the oxygen free, and allowing the carbon and the hydrogen to aggregate in woody fibre.

If the sun's rays fall upon a surface of sand, the sand is heated, and finally radiates away as much heat as it receives; but let the same beams fall upon a forest; then the quantity of heat given back is less than that received, for a portion of the sun-beams is invested in the building of the trees. Without the sun, the reduction of the carbonic acid and water can not be effected, and, in this act, an amount of solar energy is consumed exactly equivalent to the molecular work done."

Dr. Hermann Vogel, in his treatise on "The chemistry of light and photography,"* shows the chemical effect of sun-light on plants, and especially the modified growth of plants owing to differences in the intensity of light. He says, "These variations in the chemical intensity of light are very important to the life of plants. The green leaves of plants inhale carbonic acid

* D. Appleton & Co., N. Y., 1875.

and exhale oxygen under the influence of light. But this breathing process does not take place without the presence of light. The green color of leaves and the variegated scale of colors in flowers exist only under the operation of light. In the dark, plants only develop sickly blossoms, like the well known white germs of potatoes kept in cellars.

“The necessity of light for the life of plants is also seen in the effort made by plants kept in darkened rooms to reach the apertures which admit light, growing, as it were, toward them. Hence a plant developes with an energy proportioned to the intensity of the light. Accordingly, the greater fruitfulness of the tropics is to be ascribed, not only to the higher temperature, but also to the greater chemical intensity of the light. Recent observations have established that the yellow and red rays, and not the blue and violet, produce the greatest chemical effect on the leaves of plants.

“We have now arrived at the knowledge of the importance of light for the economy of nature.

“There was a time when the atmosphere was richer in carbonic acid gas than now. When the incandescent and fluid masses that once formed our earth gradually became condensed, when the watery vapors were precipitated as seas, the atmosphere contained almost all the carbon of the earth after combustion; that is, united with oxygen as carbonic acid gas. The air was, therefore, at that time infinitely richer in carbonic acid than now. When at length the earth had cooled sufficiently for vegetation to be developed, gigantic plants shot forth

from the warm ground under the influence of the sunlight. They flourished luxuriantly in the atmosphere, rich in carbonic acid, the carbon of the carbonic acid passed over into the form of wood, and thus in the course of thousands of years it was continuously diminished. Revolutions of the earth's surface succeeded; whole territories, with their forests, were buried under sand and clay beds, and, becoming decomposed, were changed into coal. A fresh vegetation sprouted forth from the newly formed soil, and again absorbed, under the influence of light, the carbonic acid of the atmosphere, to be once more engulfed by a fresh cataclysm. Thus the carbonic acid of the atmosphere was stored as coal in the depths of the earth; and thus the atmosphere, by the chemical effects of light, became continually richer in oxygen, until at length, after countless revolutions of the earth, it obtained that wealth, oxygen, which made the existence of man possible, where he appeared at the end of the earth's development.

“We see, therefore, that the chemical influence of light has played an important part in the development of our planet, and it continues to do so in the economy of nature.”

Dissipation of Energy—If we attempt to carry out in practice the theory that any form of energy may be transferred into another form without loss of useful effect, we shall be sadly disappointed. This has been the fruitless field so long cultivated by the seekers after a perpetual motion. The mistake has been made by them in this—in supposing that the various forms of

energy may be transformed into mechanical energy or made to do work without the loss incident to the absorption by the various other forms of energy which are contiguous, and which are constantly seeking fresh supplies of energy from a source higher than their own. If these processes were not only transformable but reversible, then perpetual motion would be a fact.

We know that heat, as a form of visible mechanical energy, is available only as we use it from a higher to a lower temperature, and we know further, that, once the heat has spent its energy or capacity for doing work, there is no way by which it can be restored. Heat may be made to do work, and work may be transferred into heat, but the processes are not reversible.

This does not in the least invalidate what is known as the mechanical equivalent of heat, for it takes into account all the losses incident to the transfer of available energy, but the transfer once made, complete restoration is impossible.

In all cases there is a tendency for the useful energy, whenever a transformation takes place, (28) to run down in the scale—that, the quantity being unaltered, the quality becomes deteriorated, or the availability becomes less; and from similar results in all branches of physics we are entitled to enunciate, as Sir William Thompson did very early after the new ideas were brought into full development, the principle of dissipation of energy in nature.

The principle of dissipation, or degradation, as I should prefer to call it, is simply this, that as any opera-

tion going on in nature involves a transformation of energy, and every transformation involves a certain amount of degradation (degraded energy meaning energy less capable of being transformed than before), energy is continually becoming less and less transformable.

As long as these changes are going on in nature, the energy of the universe is getting lower and lower in the scale, and you can see at once what its ultimate form must be, so far, at all events, as our knowledge yet extends. Its ultimate form must be that of heat so diffused as to give all bodies the same temperature. Whether it be a high temperature or a low temperature does not matter, because whenever heat is so diffused as to produce uniformity of temperature, it is in a condition from which it can not raise itself again. In order to get any work out of heat, it is absolutely necessary to have a hotter body and a colder one; but if all the energy in the universe be transformed into heat, and if it be in all bodies at the same temperature, then it is impossible—at all events by any process we know of as yet—to raise the smallest part of that energy into a more available form.

CHAPTER II.

THE ATMOSPHERE.

Air the Source of Oxygen for Combustion—Composition of the Air—Nitrogen—The Chemical Compounds of Oxygen and Nitrogen—Properties of Oxygen—The Physical Properties of the Atmosphere—Absorption of Moisture—Cause of Rain—Radiation of Heat through the Air—Carbonic Acid and Ammonia in the Air—Ozone.

Atmospheric Air—The source of oxygen, as a supporter of furnace combustion, is atmospheric air. The exact composition of the atmosphere has been made the subject of experimental research, and from samples taken at different heights above the level of the sea, as well as depths below it; from nearly every quarter of the globe; analysis show it to be essentially the same. The height of the atmosphere has not been accurately determined, but it is supposed to be about forty-five miles. The pressure of the atmosphere is one of its most important properties, not only in the ordinary economy of nature, but as a mechanical agency in producing draught in the furnace. The measured quantity of this pressure is found to be equal to a column of mercury having one square inch of area by thirty inches in height, or, taking the weight of the mercury instead, we then have 14.73 lb. as the weight of the atmosphere; subject, however, to changes of temperature, humidity, etc. In all ordinary calculations it is assumed that 32 feet of water, 30 inches of mercury or 15 lbs. equal the pressure of the atmosphere.

Air was long believed to be simple substance, and when its composite nature was discovered, and it was found to be a combination of nitrogen and oxygen, the first supposition was that the union was a chemical one, but farther research showed the mixture to be mechanical. We have already stated that when two bodies unite with each other chemically, the product of this combination is a compound differing from the elements of which it is composed. The union of these two gases in the proportions approximating four volumes of nitrogen to one of oxygen gives common air, and this union is distinguished by no properties which may not be attributed individually to these gases.

From this circumstance, not alone, but from the fact that every experiment to determine whether this union is a chemical one, there has been so far no indication that the union is other than mechanical.

The composition of atmospheric air varies in different localities, owing to local causes, but these changes are so minute that it is extremely difficult to detect combining gases. A mean composition of atmospheric air shows it to be composed of,

	VOLUME. PER CENT.	Wt. per Cent.
Nitrogen.....	79	77
Oxygen.....	21	23
	<u>100</u>	<u>100</u>

Aqueous vapor is present in the air at all times, even at the lowest temperatures yet observed.

From three to ten volumes of carbonic acid in ten thousand parts of air have also been observed.

The weight of one cubic foot of air at 32° Fahr. is .089723 lb. or 565.1 grains; at 62° it is .076097 lb. or 532.7 grains. The volume of one pound of air at 32° Fahr. at ordinary atmospheric pressure (14.7 lbs.) is 12.4 cubic feet.

NITROGEN—By volume and by weight nitrogen is the principal constituent of the atmosphere; it is colorless, and a little lighter than the air; the specific gravity of air being 1.0000, that of nitrogen is .9736. It is not a supporter of combustion, and its negative qualities are so gracefully given by Professor Faraday in his lectures on "The Chemical History of a Candle," that I quote: "This other part of the air is by far the larger portion, and it is a very curious body when we come to examine it; it is remarkably curious, and yet you say, perhaps, that it is very uninteresting. It is uninteresting in some respects because of this, that it shows no brilliant effects of combustion. If I test it with a taper as I do oxygen and hydrogen, it does not burn like hydrogen, nor does it make the taper burn like oxygen. Try it in any way I will, it does neither the one thing nor the other; it will not take fire; it will not let the taper burn; it puts out the combustion of everything. There is nothing that will burn in it in common circumstances. It has no smell; it is not sour; it does not dissolve in water; it is neither an acid nor an alkali; it is as indifferent to all our organs as it is possible for a thing to be. And you might say, 'It is nothing; it is not worth chemical attention; what does it do in the air?'"

“Ah! then come our beautiful and fine results shown by an observant philosophy. Suppose, in place of having nitrogen, or nitrogen and oxygen, we had pure oxygen as our atmosphere; what would become of us? You know very well that a piece of iron lit in a jar of oxygen goes on burning to the end. When you see a fire on an iron grate, imagine where the grate would go to if the whole of the atmosphere were oxygen. The grate would burn up more powerfully than the coals; for the grate itself is even more combustible than the coals which we burn in it. A fire put into the middle of a locomotive would be a fire in a magazine of fuel, if the atmosphere were oxygen. The nitrogen lowers it down and makes it moderate and useful for us, and then, with all that, it takes away with it the fumes you have seen produced from the candle, dispenses them throughout the whole of the atmosphere, and carries them away to places where they are wanted to perform a great and glorious purpose of good to man, for the sustenance of vegetation, and thus does a most wonderful work, although you say, on examining it, ‘why, it is a perfectly indifferent thing.’ This nitrogen in its ordinary state is an active element; no action short of the most intense electric force, and then in the most infinitely small degree, can cause the nitrogen to combine directly with the other element of the atmosphere, or with things round about it; it is perfectly indifferent, and therefore to say, a safe substance.”

It will be seen from the above that nitrogen plays no active part whatever in combustion—it is simply the

vessel, so to speak, in which the oxygen is delivered; the delivery having been made the vessel is no longer of any value in that connection, but the delivery is made in the body of incandescent fuel, and after its separation from the oxygen it passes on through the fire, and by virtue of its lighter gravity assists in maintaining a good draught, a matter of prime importance in furnace combustion.

Nitrogen combines with oxygen to form five distinct compounds, as below:

TABLE III.

NAME.	SYMBOL.	COMPOSITION.			
		WEIGHT.		VOLUME.	
		NITROGEN.	OXYGEN.	NITROGEN.	OXYGEN.
Nitrogen monoxide....	$N_2 O$	28	16	2	1
Nitrogen dioxide.....	$N_2 O_2$	28	32	2	2
Nitrogen trioxide.....	$N_2 O_3$	28	48	2	3
Nitrogen tetroxide.....	$N_2 O_4$	28	64	2	4
Nitrogen pentoxide....	$N_2 O_5$	28	80	2	5

Oxygen is somewhat heavier than the air, having a specific gravity of 1.1056, air being 1.0000. It is the most abundant of all the elements: it forms eight-ninths of water; nearly one-fourth of air; and about one-half of silica, chalk and alumina; the three most plentiful constituents of the earth's surface. Oxygen when free or uncombined is known only in the gaseous state. Numerous attempts have been made to reduce it to a

liquid or solid state, but so far the efforts have been fruitless.

Oxygen when pure is colorless, tasteless and inodorous. It combines with every known substance except fluorine. It is essential to the support of animal life, and is the sustaining principle of all the ordinary phenomena of combustion; and there are few experiments more brilliant than the burning of phosphorus, carbon or iron, in this gas, the products in each case being oxydized compounds of the substances burned. The weight of any compound will be found to be in all cases equal to the weight of the body burned, added to the weight of the oxygen required to effect the change.

The Physical Properties of the Atmosphere (25)*—
 “Air, although essentially an invisible substance, has weight. A room the size of Westminster hall contains as much as seventy-five tons of air. The atoms of the air are of a minuteness that is perhaps quite inconceivable by the human mind. They are much smaller than the minutest molecules that can be made visible by the microscope, and have a breadth of about the $\frac{1}{120000}$ in. They exist in what is termed the gaseous state, which means that, small as they are, they float many of their own diameters asunder, from which it arises that air is compressible by the application of mechanical force. By a pressure of fifteen lbs. upon each square inch, air is reduced to half its previous bulk, although water, by the same pressure, is only compressed the $\frac{45}{100000}$ part. Mariotte and Boyle have

*From a lecture by Dr. Mann, London.

established the law that every time the pressure upon air is doubled its volume is halved. This is the obvious reason why the air is more rare and light, bulk for bulk, at the higher regions of the atmosphere, than it is near the surface of the earth. But it is also expanded by increase of temperature, and this also by a fixed law, which is, that air is increased in volume $\frac{1}{489}$ part for each degree Fahr.; one thousand cubic inches at freezing temperature are increased to 1366.5 inches at the boiling point. The rarefaction of the atmosphere with ascent toward the higher regions is also affected according to a fixed law; at a height of three miles the air has a doubled volume and half its original density; it is again doubled in volume at about six miles high. It is probable that no animal could continue to live and breathe at a height of eight miles. The actual outer limit of the atmosphere is not certainly known.

*“Weight of the Atmosphere—*The weight of the entire atmosphere was first demonstrated by Torricelli when he made his memorable invention of the barometer. It amounts to the same as the weight of a column of mercury of the same diameter, thirty inches high. But mercury is eleven thousand times heavier than an equal bulk of air. There is nearly one ton weight of air on each square foot of the ground. The atmosphere amounts to about the $\frac{1}{1200000}$ part of the weight of the entire earth. Air, however, presses in all directions as well as down. The air is really composed of two different kinds of gasses, which mingle without interfer-

ing with each other by pressure. Each is, as it were, a vacuum to the other.

*“Vapor—*The vapor of water rises into the inter-spaces of these aerial atoms in a similarly free and unconstrained way; but more of it can be sustained in warm air than in cold. Air at a temperature of 32° can sustain the $\frac{1}{160}$ part of its own weight of aqueous vapor, but at 86° it can sustain $\frac{1}{140}$ part of its own weight. The barometer gives the combined weight of the oxygen, nitrogen, and gaseous vapor of the air, and the portion of this weight which is due to aqueous vapor is called the elastic force of vapor. With a barometer standing at 30.000 inches, and with a hygrometer indicating an elastic force of vapor of 0.450, very nearly one-quarter lb. of the entire pressure of fifteen lbs. on each square inch is due to the vapor. When more vapor is generated than can be at once carried away, the barometer necessarily rises; when vapor is condensed in the atmosphere, the barometer falls; when the temperature of saturated air is reduced from 80° to 60° , five grains of aqueous vapor are deposited from each cubic foot. This is the effective cause of rain. Warm air drinks up vapor and carries it away, and subsequently deposits it when it comes to some region where it gets chilled.

“The Temperature of the air decreases with height, about 1° for each three hundred feet or four hundred feet ascended; this is because the air gets further from the source of heat, and also because heat is absorbed

above to maintain the expansion of the air. Sensible heat is lost on the expansion of air, and is produced on its condensation. Pure air is virtually quite pervious to heat; none stops in the air, but all passes through. Aqueous vapor, on the other hand, acts as a screen to heat. Prof. Tyndall has shown that ten per cent. of the solar heat radiated from the earth through a moist atmosphere is stopped within ten feet of the ground. The absolute diathermaney of dry air accounts for the scorching heat of mountain tops, as the retentive power of aqueous vapor does for the soft heat of low lying regions in the tropics. The rain deluges of equatorial calms are due to the radiation of heat through the upper dry layers of the atmosphere. Cumuli clouds are formed from the same cause; they are the capitals of invisible columns of saturated air. Mountain tops are condensers of moisture for a similar reason.

“*Carbonic Acid*—There is in air, besides the aqueous vapor, 3.36 parts in every ten thousand of carbonic acid gas, and three and a-half parts in every ten millions of ammonia. Small as these quantities appear, they are sufficient to produce very astonishing results; there are one million three hundred thousand tons of carbonic acid, containing three hundred and seventy-one thousand four hundred and seventy-five tons of carbon in the air, which rests upon each square mile of the earth, and thirty lbs. of ammonia are carried down by the rain to each acre of land every year.

“*Ozone*—There is one part of ozone in every seven hundred parts of air; but this ozone is in reality only a condensed form of oxygen itself; three volumes of oxygen are condensed to form two volumes of ozone. It is oxygen in an increased state of activity.

“*The Diathermancy and Transparency* of the air are both of the very highest importance to the life existing upon the earth. It is its diathermancy which enables the sun’s heat to reach the terrestrial surface for the performance of its marvelous operations. It is its transparency which renders the air the window of the earth, giving man his outlook into space and admitting the wonderful effects of color and light. If the air were not transparent, all nature would be in a perpetual dense fog. The blueness of the sky is due to the weak blue rays of light being arrested by the air and its transparent vapors, and turned back upon the earth. The brilliant sun-set colors are similarly due to the arrest and reflection of the stronger yellow and red vibrations, by the denser vapors of the clouds.”

CHAPTER III.

FUELS.

Classification of Fuel—Wood—Water Present in Wood—Composition of Wood—Wood Charcoal—Combustibility of Wood Charcoal—Peat—Analysis of Peat—Products of the Distillation of Peat—Peat as a Fuel—Peat Charcoal—Lignite—Difference between Lignite and Brown Coal—Lignite as a Fuel—Water in Lignite—Analysis of Lignites—Classification of Coal—Bituminous Coal—Analysis of Bituminous Coals—Non-caking Coals—Block Coal—Caking Coals—Gas Coal—Coke—The Influence of Temperature and Pressure in the yield of Coke—Cannel Coal—Semi-bituminous Coal—Semi-anthracite Coal—Anthracite Coal.

FUEL is a word employed to express, in general terms, any substance which may be economically burned by means of atmospheric air to generate heat. The economic value of any fuel will depend upon its heating power. The two elements contributing this property to fuel are carbon and hydrogen. The more important varieties of fuel include wood, peat, lignite and coal. These are classed by Dr. Percy as follows:

CLASSIFICATION OF FUELS.

Wood.

Peat.

Coal.	{	Lignite.	{	Non-caking, rich in oxygen.
		Bituminous.		Caking.
		Anthracite.		Non-caking, rich in carbon.

Carbonization. Products of	Solid.	Wood—charcoal.
		Peat—charcoal.
		Coke.
	Volatile.	Carbonic Oxide.
		Hydrogen.
		Hydro-carbon.

WOOD, as a fuel, may be divided into two classes, hard and soft.

Hard woods include compact, heavy woods—like oak, hickory, beech, elm, ash, walnut.

Soft woods include pine, birch, poplar, willow.

Freshly cut green wood contains on an average about forty-five per cent. of moisture, often more, though sometimes less; and after long exposure to the atmosphere under favorable conditions it still retains from eighteen to twenty per cent. of moisture. This is a point of great practical importance in reference to the direct application of wood as fuel. The following table, prepared by M. Violette, shows the proportion of water expelled from wood at gradually increasing temperatures:

TABLE IV.

TEMPERATURE.	WATER EXPELLED FROM ONE HUNDRED PARTS OF WOOD.			
	OAK.	ASH.	ELM.	WALNUT.
257° Fahr.....	15.26	14.78	15.32	15.55
302° Fahr.....	17.93	16.19	17.02	17.43
347° Fahr.....	32.13	21.22	36.94?	21.00
392° Fahr.....	35.80	27.51	33.38	41.77?
437° Fahr.....	44.31	33.38	40.56	36.56

The wood which M. Violette operated upon had been kept in store during two years.

In each experiment the specimens were exposed during two hours to dessication in a current of super-heated steam, of which the temperature was gradually raised from 257° to 437° Fahr. When wood, which has been strongly dried by means of artificial heat, is left exposed to the atmosphere, it re-absorbs about as much water as it contains in its air-dried state.

TABLE V—SHOWING THE COMPOSITION OF WOOD.

ANALYSIS BY M. EUGENE CHEVANDIER.

WOODS.	COMPOSITION.				
	CARBON.	HYDROGEN	OXYGEN.	NITROGEN.	ASH.
	PER CENT.	PER CENT.	PER CENT.	PER CENT.	PER CENT.
Beech	49.36	6.01	42.69	0.91	1.00
Oak	49.64	5.92	41.16	1.29	1.97
Birch	50.20	6.20	41.62	1.15	0.81
Poplar	49.37	6.21	41.60	0.96	1.86
Willow.....	49.96	5.96	39.56	0.96	3.37
Average.....	49.70	6.06	41.30	1.05	1.80

Where wood is protected from the atmosphere and heated to about 600° Fahr., its gaseous or volatile elements are driven off, and a fixed residue called charcoal remains.

Good charcoal is black; gives a sonorous ring when struck; breaks with more or less conchoidal fracture; is easily pulverizable, but does not crumble under mod-

erate pressure; floats on water, and does not burn with flame when ignited in separate pieces.

TABLE VI—SHOWING THE COMPOSITION OF CHARCOAL PRODUCED AT VARIOUS TEMPERATURES (2).

BY M. VIOLETTE.

TEMPERATURE OF CARBONIZATION.	COMPOSITION OF THE SOLID PRODUCT.				CARBON FOR A GIVEN WEIGHT OF WOOD.
	CARBON.	HYDROGEN	OXYGEN, NITROGEN AND LOSS.	ASH.	
FAHRENHEIT.	PER CENT.	PER CENT.	PER CENT.	PER CENT.	PER CENT.
302° }	47.51	6.12	46.29	0.08	47.51
392* }	51.82	3.99	43.98	0.23	39.88
482.....	65.59	4.81	28.97	0.63	32.98
572.....	73.24	4.25	21.96	0.57	24.61
662.....	76.64	4.14	18.44	0.61	22.42
810.....	81.64	4.96	15.24	1.61	15.40
1873.....	81.97	2.30	14.15	1.60	15.30
2012.....	83.29	1.70	13.79	1.22	15.32
2282.....	88.14	1.42	9.26	1.20	15.80
2372.....	90.81	1.58	6.49	1.15	15.85
2732.....	94.57	0.74	3.84	0.66	16.36
Melting point of } platinum..... }	96.52	0.62	0.94	1.95	14.47

The wood experimented on was that of black alder or alder buckthorn, which furnishes a charcoal suitable for gunpowder.

Combustibility of Wood-charcoal—M. Violette states that charcoal made at 500° Fahr. burns most easily; and that made between 1832° and 2732° Fahr. can not be

* The products obtained at these temperatures can not properly be termed charcoal.

ignited like ordinary charcoal. Charcoal made at a constant temperature of 572° Fahr. takes fire in the air when heated to between 680° and 716° Fahr., according to the nature of the wood from which it has been derived; charcoal from light woods, other things be equal, igniting most easily.

PEAT OR TURF—Peat is composed of various kinds of plants which are undergoing a gradual transformation by a process of slow burning or carbonization, in which the oxygen of the plants is being liberated under special conditions of moisture and heat, leaving a spongy carbonaceous mass, in which the remains of the plants are often so well preserved that species may easily be distinguished. The formation of peat may be regarded as one of the most important geological changes now in evident progress. Immense accumulations of peat exist in various parts of the world. Within two miles of South Bend, Indiana, is the eastern terminus of one of the most extensive peat beds known, (4) being three miles in width and extending westward down the valley of the Kankakee for more than sixty miles, varying from five to fifty feet in thickness.

In color, peat varies from a yellowish-brown through all gradations to a very dark brown, almost black. The former in structure is light, spongy and fibrous; the latter is more compact and pitchy in its appearance, the fibrous texture being almost entirely obliterated. In advanced stages of decomposition it is compact and dense, presenting an earthy fracture when broken; in general the darker the peat the richer it is in carbon.

Peat formations are confined to cold and temperate climates, and swampy ground. In its natural and more advanced state, peat contains about three-fourths of its own weight of water; in the earlier stages of decomposition the quantity of water present often amounts to as much as ninety per cent. of the whole weight, and is totally unfit for any of the purposes for which fuel is employed.

Very little use has been made of peat in this country, owing to the abundance, cheapness and superior heating power of coal. In Ireland, Germany, Sweden and other foreign countries, it is used largely not only for domestic, but for metallurgical purposes.

The following analysis of Irish peat is upon the authority of Sir Robert Kane:

TABLE VII—CHEMICAL COMPOSITION OF IRISH PEAT (2).
PERFECTLY DRY.

DESCRIPTION AND LOCALITY OF PEAT.	SPECIFIC GRAVITY.	CARBON.	HYDROGEN.	OXYGEN.	NITROGEN.	ASH.
		PER CENT.	PER CENT.	PER CENT.	PER CENT.	PER CENT.
1. Light surface, Philipstown.....	.405	57.52	6.83	32.23	1.42	1.99
2. Rather dense, Philipstown.....	.669	58.56	5.91	31.40	0.85	3.30
3. Light surface, Wood of Allen.....	.335	58.30	6.43	31.36	1.22	2.74
4. Compact and dense, Wood of Allen...	.655	56.34	4.81	30.20	0.74	7.90
5. Light fibrous, Tickneven.....	.500	58.60	6.55	30.50	1.84	2.63
6. Light fibrous, Upper Shannon.....	.280	58.53	5.73	32.32	0.93	2.47
7. Very dense, compact, Upper Shan'on	.853	59.42	5.49	30.50	1.64	2.97
Averages.....	.528	58.18	5.96	31.21	1.23	3.43

TABLE VIII—SHOWING THE PRODUCTS OF DISTILLATION OF THE IRISH PEATS GIVEN IN TABLE NO. VII.

DESCRIPTION AND LOCALITY OF PEAT.	WATER.	CRUDE TAR.	CHARCOAL.	GAS.
	PER CENT.	PER CENT.	PER CENT.	PER CENT.
Nos. 1 and 2, Philipstown.....	23.6	2.0	37.5	36.9
No. 3, Wood of Allen	32.3	3.6	39.1	25.0
No. 4, Wood of Allen	38.1	2.8	32.6	26.5
No. 5, Tickneven.....	33.6	2.9	31.1	32.3
No. 6, Upper Shannon.....	38.1	4.4	21.8	35.7
No. 7, Upper Shannon.....	21.8	1.5	19.0	57.7
Averages	31.4	2.8	29.2	36.6

The tar, when re-distilled, yielded water, paraffine, oils, charcoal and gas.

The water yielded chloride of ammonium, acetic acid and wood-spirit.

In a French report on the use of peat as a fuel for locomotives, after experimenting on a large scale, the conclusion was reached that an economy of nearly one-half might be effected over a similar mileage and tonnage with coal; setting aside the greatly reduced injury to boilers, flues and grates. It is also claimed for peat in this report that, the firing once understood, is much more easily managed than coal; requiring no stoking; the heat being more regular, and not subject to the sudden changes in intensity that occur so frequently with coal and coke, and which changes injure the furnaces.

Peat Charcoal—The charcoal produced by the carbonization of ordinary *air-dried peat* is very friable and porous; it takes fire very readily, and when ignited nearly always continues to burn until its carbonaceous matter is wholly consumed; it scintillates in a remarkable degree when burned in a smith's fire; its extinction when in mass is difficult, and hence this is the troublesome part of its manufacture by the usual method of carbonization in piles; and it is so little coherent that it can not be conveyed without much of it being crushed to dust (20).

LIGNITE—Is classed among mineral coals, and occupies a position historically between peat and bituminous coal. It is not synonymous with brown coal, proper, though there are many points of similarity. It is believed to be of later origin than bituminous coal and is in a less advanced stage of decomposition; the woody-fibre and vegetable texture of lignite is almost entirely wanting in coal, though there is little doubt that they are of one common origin. The chemical difference between lignite and brown coal may be determined by dry distillation, in which the former yields acetic acid, and acetate of ammonia, whereas, coal produces only ammonical liquor (5). Woody fibre gives rise to acetic acid; lignite must, therefore, still contain undecomposed woody fibre. Lignite and brown coal belong chiefly to the cretaceous and tertiary periods. Lignite varies considerably in appearance and structure, usually, however, preserving a wood-like appearance when broken, the fracture is uneven presenting a brown to a very dark brown-black

color, with a dull and frequently a fatty lustre. It easily breaks or crumbles in handling, and will not bear rough transportation to great distance; neither will it bear long continued exposure to the weather; crumbling rapidly.

It can be coked but the coke is not of good quality, though some lignites coke better than others.

As a fuel it must be used in its natural state, and near where it is mined, to obtain the best results. It will be noticed in examining the annexed tables that it contains a large per cent. of volatile matter and water. It may be deprived of this water by heating the lignite above the boiling point of water, but if a piece so heated is afterwards allowed to remain in the open air it will again absorb from the atmosphere the same quantity of water as that driven off by the heat.

It is non-caking in the fire, and yields but a moderate heat, that is, its heating power in general is below that of ordinary bituminous coals.

The number of units of heat in lignite of different qualities and from different parts of the world are given in the tables, and its relative heating power may be easily determined as compared with coal of a known calorific value. It must not be forgotten in making use of the figures in the columns of units of heat in these tables, that it is the theoretical numbers which are given after the water in the specimen had been expelled by heat, the quantity of heat so expended in its evaporation does not appear in the calculation.

Lignite contains from ten to twenty per cent. of water, which must be evaporated in the fire before any useful effect is obtained, and, at a considerable loss, so this must be taken into account in any comparison made with other fuels.

The use of lignite in this country is so limited that it has at present little or no commercial value except in the immediate vicinity where it is mined; but as the vast territories west of the Mississippi are developed it will then become a matter of growing importance, as lignite must become their chief fuel, after the disappearance of the forests. Very extensive deposits occur in California, Colorado, Nevada, Utah, Wyoming, New Mexico, Oregon and Alaska.

Kentucky—Lignite from the bluff of Fort Jefferson, Ballard county, Kentucky.

PROXIMATE ANALYSIS BY PROFESSOR E. T. COX.

Specific gravity.....	1.201	
		PER CENT.
Fixed carbon.....	40.	
Volatile combustible matter.....	23.	
Water.....	30.	
Ash, reddish yellow or flesh tint.....	7.	
	<hr/>	
	100.	
Total volatile matter.....	53. per cent.	
Coke, reduced in bulk and nearly the		
same shape as the original specimen	47. per cent.	
	<hr/>	
	100.	

Some of this lignite has very much the appearance of coal; hence, it is apt to be mistaken for it; but it

is of much more recent date than true coal, and has been formed under entirely different circumstances, and derived from a very different vegetation than that which flourished during the carboniferous era.

Washington Territory—A sample of Billingham Bay coal, Washington Territory, was sent by Dr. John Evans to Professor E. T. Cox, who made both proximate and ultimate analyses of it, with results as given below:

PROXIMATE ANALYSIS.

	PER CENT.
Fixed carbon.....	58.25
Volatile combustible matter.....	31.75
Water.....	7.00
Ashes, reddish brown.....	3.00
	<hr/> 100.00
Coke.....	61.25 per cent.
Volatile matter.....	38.75 per cent.
The coke slightly shrunken, dull black.	

This is to be regarded as lignite rather than a true coal; it may be handled without much loss, has a bedded structure; layers about one-eighth inch thick, sometimes defined by a thin scale of carbonate of lime. Color, glossy black; fracture, slaty and parallel to stratification, in the opposite direction the fracture is irregular and brittle. This formation has much less earthy matter than most tertiary coals or lignites, and much more carbon.

ULTIMATE ANALYSIS.

	FIRST SAMPLE.	PER CENT.
Carbon.....		68.454
Hydrogen.....		6.666
Sulphur.....		1.000

Water (at 212°).....	7.000
Ashes.....	3.400
Oxygen, nitrogen and loss.....	13.480
	<hr/> 100.000

SECOND SAMPLE.	PER CENT.
Carbon.....	67.090
Hydrogen.....	4.555
Sulphur.....	1.000
Water (at 212°).....	7.000
Ashes.....	3.100
Oxygen, nitrogen and loss.....	17.355
	<hr/> 100.000

This coal (or lignite) contains a large amount of oxygen and is deficient in the amount of hydro-carbons, and therefore, more difficult of ignition than most of the western bituminous coals, but it is rich in fixed carbon in the coke and will therefore be a durable coal. It is intermediate in composition of its ultimate elements to cannel coal and lignites.

Vancouver's Island—Lignite, color, dull black, sub-metallic; fracture, foliated and slaty, numerous partings filled with scales of carbonate of lime.

PROXIMATE ANALYSIS BY PROFESSOR E. T. COX.

	PER CENT.
Fixed carbon.....	62.
Volatile combustible matter.....	31.
Water.....	4.
Ash, reddish brown.....	3.
	<hr/> 100.
Coke.....	65 per cent.
Volatile matter.....	35 per cent.

This lignite shrinks slightly in coking, and is dull black in color.

Colorado—Lignite from Carbon City on the Union Pacific Railroad. Specimen brought by Edward King.

ANALYSIS BY PROFESSOR E. T. COX.

Color, jet black—specific gravity.....	1.271
Weight, one cubic foot.....	80.68 lbs.
	PER CENT.
Fixed carbon.....	41.25
Volatile combustible matter.....	46.00
Water.....	3.50
Ash, lead color.....	9.25
	<hr/> 100.00
Coke.....	50.50 per cent.
Volatile matter.....	49.50 per cent.
Coke—shrivelled, cracked, lusterless.	

Colorado—Lignite from Canon City, about two hundred miles south of Denver City.

PROXIMATE ANALYSIS BY PROFESSOR E. T. COX.

Color, jet black—specific gravity.....	1.279
Weight, one cubic foot.....	79.23 lbs.
	PER CENT.
Fixed carbon.....	56.80
Volatile combustible matter.....	34.20
Water.....	4.50
Ash, ochre yellow.....	4.50
	<hr/> 100.00
Coke.....	61.30 per cent.
Volatile matter.....	38.70 per cent.
Coke—slightly swollen, unchanged, semi-lustrous.	

This is a good fuel.

Arkansas—Lignite from Ouachita county. This lignite has a rather rhomboidal cleavage; can be cut with a knife, and receives a good polish, which gives it a much blacker appearance. It is solid, heavy, compact, of a bluish-brown color, disintegrating, however, by exposure to the atmosphere.

PROXIMATE ANALYSIS BY PROFESSOR E. T. COX.

	PER CENT.
Fixed carbon.....	34.50
Volatile combustible matter.....	28.50
Water (at 260°).....	32.00
Ashes.....	5.00
	<hr/> 100.00
Coke.....	39.5 per cent.
Volatile matter.....	60.5 per cent.

This lignite was distilled in a small iron crucible, to which a glass receiver was attached and kept cool with water. The first product that came over was gas having a feeble odor of sulphurous acid and burning with a tolerably bright flame. The gas was soon accompanied by ammoniacal water, a yellowish oil, and a waxy product; the latter rising into the exit pipe of the glass receiver whenever the fire was a little too strong, which proves it to be very volatile; but when condensed, it has the consistency of lard, and the color of beeswax. The last products which came over were lubricating oil and paraffine.

Three thousand seven hundred grains of this lignite gave:

	GRAINS.	PER CENT.
Coke.....	1,400	37.83
Watery solution, containing sulphurous acid, organic acids, and ammonia....	1,270	34.32
Crude oil.....	450	12.16
Gas and loss.....	580	15.69
	<hr/> 3,700	<hr/> 100.00

From this analysis two thousand pounds of lignite would yield 35.40 gallons crude oil.

Occasionally small segregations are found in the lignite, approaching amber and retin-asphaltum; in fact, much of the coal has a retin-asphaltum aspect.

Kentucky—Brown coal (lignite?), sample from one and a-half miles north-west of Blandville, Ballard county.

PROXIMATE ANALYSIS BY PROFESSOR E. T. COX.

Specific gravity, 1.173.

	PER CENT.
Fixed carbon.....	31.0
Volatile combustible matter.....	48.0
Water.....	11.5
Ash, white.....	9.5
	<hr/> 100.00

Coke..... 40.5 per cent.

Volatile matter..... 59.5 per cent.

This coal contains from twenty to thirty per cent. less fixed carbon than the coals of the carboniferous epoch, and usually a much larger quantity of hygrometric moisture, which renders them inferior as fuel and still less applicable for the generation of steam, and manufacturing purposes generally.

A specimen from Robertson county, Texas, taken from a seam ten feet thick, was analyzed, and is described by Professor E. T. Cox (4), as a lusterless, dull brown coal with irregular fracture and much inclined to shrink, crack and fall to pieces on exposure to the air. It contained by proximate analysis,

	PER CENT.
Fixed carbon.....	45.00
Gas.....	39.50
Water.....	11.00
Ash, white.....	4.50
	<hr/>
	100.00
Coke.....	49.50 per cent.
Volatile matter.....	50.50 per cent.
Heat units.....	13,068
Specific gravity.....	1.232
Weight of one cubic foot.....	77 lbs.
Coke—slightly shrunken, lusterless, and bears a close resemblance to wood charcoal.	

TABLE IX—SHOWING THE ANALYSIS AND HEATING POWER OF DIFFERENT LIGNITES, AS DETERMINED
BY M. REGNAULT (2).

DESCRIPTION.	LOCALITY.	SPECIFIC GRAVITY.	COKE.		COMPOSITION.					HYDROGEN IN EXCESS.	HEATING POWER.
			PER CENT.	NATURE.	CARBON.	HYDROGEN.	OXYGEN AND NITROGEN.	ASH.			
			PER CENT.		PER CENT.	PER CENT.	PER CENT.	PER CENT.	PER CENT.	PER CENT.	HEAT UNITS.
Perfect Lignite.....	Dax, South of France.....	1.272	49.1	Pulverulent.....	70.49	5.59	18.93	4.99	3.92	12,312	
	Mouths of the Rhone	1.254	41.1	Pulverulent.....	63.88	4.58	18.11	13.43	2.41	10,782	
	Hessen-Cassel, (Mount Mesiner)...	1.351	48.5	Pulverulent.....	71.71	4.85	21.68	1.77	2.25	11,826	
	Lower Alps	1.276	49.5	Pulverulent.....	70.02	5.20	21.67	3.01	2.59	11,790	
	Greece	1.185	38.9	Like wood charcoal.....	61.20	5.00	24.78	9.02	2.03	10,161	
Imperfect Lignite	Cologne.....	1.100	36.1		63.29	4.98	26.24	5.49	1.83	10,337	
	Usnack (fossil wood).....	1.167	.....		56.04	5.70	36.07	2.19	1.38	9,005
Lignite passing into bitumen....	Elbogen, Bohemie.....	1.157	27.4	Porous.....	73.79	7.46	13.79	4.96	5.81	14,337	
	Cuba.....	1.197	39.0	Porous.....	75.85	7.25	12.96	3.94	5.70	14,562	
Asphalte.....	Mexico.....	1.063	9.0	Porous.....	79.18	9.30	8.72	2.80	8.26	16,655	

CLASSIFICATION OF COAL.

Coals are classified according to the amount of carbon and volatile matter present in their composition; the following is the classification adopted by Professor H. D. Rogers, in the "Geology of Pennsylvania":

Anthracites.....	{	Hard Anthracites.
		Semi or Gaseous Anthracites.
Common Bituminous Coal.....	{	Semi-bituminous coals.....
		Bituminous coal
	{	Semi-bituminous cherry coal, and
		Semi-bituminous splint coal.
	{	Caking coal.
		Cherry coal.
		Splint coal.
Hydrogenous or Gas coals.....	{	Cannel coals. [hill, etc.)
		Hydrogenous Shaly coal (Torbane-
		Asphaltic coal (Albert Mine.)

BITUMINOUS COAL—When coal contains as much as eighteen or twenty per cent. of volatile combustible matter it is called bituminous. The passage of lignite into bituminous coal is as gradual as that of bituminous coal into anthracite, so there is no precise line of demarkation between these classes of coal. Some bituminous coals yield upon analysis as much and occasionally more than fifty per cent. of volatile matter. It may be said, however, to range from twenty to fifty per cent., and will hardly admit of averaging, as scarcely any two mines yield coal of the same quality. The amount of volatile matter in bituminous coal can not be judged from its appearance simply, and perhaps the easiest and best way to arrive at it, and to determine

the amount of fixed carbon at the same time, is by proximate analysis.

The use of the word bituminous is somewhat misleading: there is no bituminous coal in this country, which contains any bitumen in its composition. In general, this word is applied to such coals as have a large proportion of organic elements in addition to its fixed carbon, and includes all the hydro-carbons, water and nitrogen, in its composition.

The true bitumens are destitute of organic structure; they appear to have arisen from coal or lignite by the action of subterranean heat, and very closely resemble some of the products yielded by the destructive distillation of those bodies. They are very numerous, and have yet been but imperfectly studied.

It is possible that its name has been applied to coal on account of a similarity between the burning of a coal rich in hydro-carbon and bitumen. The latter is very inflammable, and burns with a red, smoky flame.

Professor Rogers, in his *Geology of Pennsylvania*, makes a distinction between what he calls common bituminous coals and hydrogenous or gas coals. His scheme of classification will be found on page 52. It is scarcely possible to give in a single description the physical properties of bituminous coal, which will be applicable to all varieties.

In external properties, (23) the common bituminous coals range in color from a pitch black to a dark brown; their luster is vitreous, resinous, or, in the more fibrous varieties, silky; their structure is compact or cuboidal,

slaty, columnar, and even fibrous; and their fracture, irrespective of structural joints and cleavage, is conchoidal, and often flat and rectangular, and sometimes fibrous. It is distinctive of these coals to burn with more or less of yellow bituminous flame and smoke, and to emit, when burning, a bituminous odor. In *proximate composition*—namely, in fixed carbon or coke, volatile matter or combustible gases, and earthy sedimentary residue or ashes—they may be regarded as ranging between the following general limits:

Fixed carbon.....from 52 to 84 per cent.

Volatile matter.....from 12 to 48 per cent.

Earthy matter.....from 2 to 20 per cent.

Sulphur.....from 1 to 3 per cent.

Dried at a temperature of 212° Fahr., the yield of water is from one to three or four per cent.

The proportion of earthy matter is of course too variable to have a maximum limit affixed to it, as all the kinds of coal may, by impurities, graduate into carbonaceous shales.

In *ultimate composition*, the coals of this class may be recorded as ranging approximately nearly thus—

Carbon.....75 to 80 per cent.

Hydrogen.....5 to 6 per cent.

Nitrogen.....1 to 2 per cent.

Oxygen.....4 to 10 per cent.

Sulphur.....0.4 to 3 per cent.

Ash.....3 to 10 per cent.

COMPOSITION OF VARIOUS BITUMINOUS COALS.

ILLINOIS.

Smith's, Warren county. Dr. Norwood.

	PER CENT.
Fixed carbon.....	51.7
Volatile matter.....	43.1
Earthy matter	5.2
	<hr/>
	100.0
Ashes, red.	
Specific gravity, 1.24.	

Montauk Coal—A compact, deep black, caking coal, laminæ very indistinct, breaks into irregular cubes, and contains some pyrites. E. T. Cox.

	PER CENT.
Fixed carbon.....	48.00
Gas	35.00
Water.....	11.50
Ash, brown.....	5.50
	<hr/>
	100.00
Coke	53.50
Heat, units.....	12,760
Specific gravity.....	1.232
Weight of one cubic foot.....	77 lbs.
Coke: puffed, lusterless, amorphous.	

Bureau county, Illinois. Dr. V. Z. Blandy.

	PER CENT.
Fixed carbon.....	57.6
Volatile matter.....	28.8
Moisture.....	11.2
Ash, nearly white.....	2.4
	<hr/>
	100.0

Coke—Close, not swollen.

Specific gravity, 1.316.

Weight of a cubic foot..... 80 lbs.

The heat units in this coal, determined as below, are:

Carbon.....	$.576 \times 14,544 =$	.....	8,377
Volatile matter.....	$.288 \times 20,115 =$		5,793
Less.....	$.288 \times 3,600 =$	1,037	4,756
Total heat units.....			13,133

Mercer county, Illinois. Dr. V. Z. Blandy.

	PER CENT.
Fixed carbon.....	54.8
Volatile matter.....	31.2
Moisture.....	8.4
Ash, fawn color.....	5.6
	100.0

Coke—pulverulent between the fingers.

Specific gravity, 1.259.

Weight of a cubic foot..... 78.49 lbs.

Heat units..... 13,123

INDIANA.

McClellan and Zellers' Coal, north of Brazil, Clay county. This is a typical block coal, a dull, lusterless black, in thin laminae, separated by fibrous charcoal partings, very strong across the bedding lines, free from pyrites and calcite, and is highly esteemed for blast and puddling furnace use. The specimen analyzed was fresh from the mine and held a large excess of water which, on exposure to the air of the laboratory for a few weeks, would reduce to about 3.5 per cent. E. T. Cox.

	PER CENT.
Fixed carbon.....	56.50
Gas.....	32.50
Water	8.50

Ash, white.....	2.50
	<hr/> 100.00
Coke.....	59.00
Heat units, wet coal.....	13,588
Heat units, dry coal... ..	14,400
Specific gravity.....	1.285
Weight of one cubic foot.....	80.31 lbs.
Coke—lamineate, not swollen, lusterless.	

INDIANA.

Elias Coopriders Coal, near Middletown, Clay county. This is a compact, jet-black, slightly laminate, caking coal, with some evidence of pyrites in the lower part. E. T. Cox.

	TOP.	MIDDLE.	BOTTOM.
Fixed carbon.....	44.00	45.00	50.50
Gas.....	47.50	44.00	42.50
Water	4.00	2.50	3.00
Ash..... pink	4.50	brown 8.50	yellow 4.00
Coke, per cent.....	48.50	53.50	54.50
Heat units.....	14,263	13,811	14,364
Specific gravity.....	1.280	1.533	1.211
Weight of one cubic foot.....	80.00	95.81	75.68

Coke: Vitreous, puffed, amorphous.

PENNSYLVANIA.

Connellsville Coal, Fayette county. From this coal the celebrated foundry coke is made. The specimen received would measure about one-half a cubic foot; every part of it displayed prismatic colors; it had a columnar structure, inclined to be granular, and easily broken into small fragments. E. T. Cox.

	PER CENT.
Fixed carbon.....	65.00
Gas.....	24.00

Water	4.50
Ash, white.....	6.50
	<hr/>
	100.00
Coke	71.50
Specific gravity.....	1.28
Weight of one cubic foot.....	80.00
Coke: Of steel gray color, columnar, very strong, dense, slightly puffed on the surface.	

The heat units in this coal are :

		PER CENT.
Carbon	$.65 \times 14,544 =$	9,454
Volatile matter	$.24 \times 20,115 =$	4,828
Less.....	$.24 \times 3,600 =$	864
		<hr/>
Total heat units		13,418

Youghiogheny Coal, Pennsylvania. Geological survey of Kentucky. Professor Peter.

	PER CENT.
Fixed carbon.....	58.40
Volatile combustible matter.....	35.00
Moisture.....	1.00
Ashes.....	5.60
	<hr/>
	100.00

The heat units in this coal are :

Carbon	$.584 \times 14,544 =$	8,494
Volatile matter.....	$.35 \times 20,115 =$	7,040
Less	$.35 \times 3,600 =$	1,260
		<hr/>
Total heat units.....		14,274

This is considered a very superior gas coal, and furnishes a quality of coke highly valued for domestic use.

PENNSYLVANIA.

Stone's Gas Coal, Fayette county. This coal is in common use in many cities in the western states for the

manufacture of illuminating gas. The specimen analyzed was obtained at the Indianapolis gas works, and said, by the superintendent, to be first-class. E. T. Cox.

	PER CENT.
Fixed carbon.....	58
Gas	34
Water	3
Ash, white.....	5
	<hr/> 100
Coke.....	63 per cent.
Heat units.....	14,049
Specific gravity.....	1.292
Weight of one cubic foot.....	80.75 lbs.
Coke: slightly puffed, amorphous, lusterless, and is much esteemed as a grate and stove fuel.	

KENTUCKY.

Coal from Sardric and Mud river, Mecklenburg county. This is a dull black, vitreous, caking coal, with irregular, resinous fracture, laminæ indistinct, no visible pyrites. E. T. Cox.

	SARDRIC.	MUD RIVER.
Fixed carbon.....	51.00	57.00
Gas	42.50	37.00
Water.....	2.00	3.50
Ash, white	4.50	2.50
Coke.....	55.50	59.50
Heat units.....	14,436	14,400
Specific gravity.....	1.325	1.280
Weight of one cubic foot.....	82.81 lbs.	80.00 lbs.
Coke: Puffed, lusterless, amorphous.		

OHIO.

Coal from Nelsonville—From the Geological Report, 1869.

ANALYSIS BY PROF. T. G. WORMLEY.

	PORTION OF THE SEAM.		
	BOTTOM.	MIDDLE.	TOP.
Specific gravity	1.285	1.272	1.284
Water	6.20	6.65	5.00
Volatile matter.....	31.30	33.05	32.80
Fixed carbon.....	59.80	58.40	53.15
Ash.....	2.70	1.90	9.05
Total.....	100.00	100.00	100.00
Sulphur.....	0.97	0.41	0.94
Color of ash.....	Gray.	Yellow.	Gray.
Nature of the coke.....	Compact.	Compact.	Compact.
Cubic feet of permanent gas per pound of coal	3.56	3.24	4.95

An average of the above three samples gives,

Volatile matter..... .3238 per cent.

Fixed carbon..... .5712 per cent.

Then, taking 14,544 as the heat units in carbon (as has been done in the preceding examples), and 20,115 as the heat units of the combustion of the combined volatile matter, deducting 3,600 units for the heat expended in their expulsion, we have,

Carbon $.5712 \times 14,544 =$ 8,308

Volatile matter..... $.3238 \times 20,115 =$ 6,513

Less..... $.3238 \times 3,600 =$ 1,166 5,347

Total heat units in one pound of coal..... 13,655

CLASSIFICATION OF BITUMINOUS COALS.

It will serve our present purpose if we divide all bituminous coals into two classes :

CAKING AND NON-CAKING.

Caking coal is the name given to any coal which when heated the lumps seem to fuse together, and swell in size, having a pasty appearance and emitting a gummy or sticky substance over the surface, liberating small streams of gas which appear to escape from a considerable pressure from the interior of the coal, and which burn with a bright yellow and sometimes a reddish flame, terminating in smoke. A characteristic of caking coal is that lumps, either large or small, being rendered pasty by the action of the heat, will cohere in the fire and form a spongy looking mass, which, not unfrequently, covers almost the whole surface of the grate. This is the property called caking. Caking coals rich in hydro-carbons are highly esteemed by gas manufacturers.

Gas Coal—The following on the requisites of a gas coal is from the pen of Mr. James McFarlane: (18)

“The most important requisites of gas coal are, first, that it contain a large amount of volatile combustible matter, or gas; second, that the volatile matter be of a good illuminating power; third, that the coal be as free as possible from sulphur; and fourth, that the coke furnished by the carbonization of the coal be bulky, and at the same time firm, that is, not inclined to be granular.

“1. The percentage of the volatile matter in the coals usually employed in gas-making is from twenty-five to forty, and in cannel coal it rises to sixty or seventy per cent., a portion being nitrogen and oxygen. A ton of coal should produce from eight thousand to nine thousand feet of carbureted hydrogen or illuminating gas, or from four to four and half feet per pound, the latter, as is well known, being the product of a fair average sample of Youghioghenny coal. Gas works practically obtain more gas per pound than the chemists in analyzing the coal, doubtless through the re-distillation of tarry matter and its conversion into permanent gas. Besides this, at gas works the measurement is taken at a high temperature, a difference of five degrees changing the volume of gas about one per cent. By using the steam-jet exhaust (a recent improvement) an increased quality of gas is obtained, which would otherwise pass off in little bubbles in the tar.

“2. That the gas produced from the coal be of good illuminating power is very important. The standard of gas in our large cities ranges from fourteen to sixteen candle power. The standard candle in testing gas is of spermaceti, burning at the rate of one hundred and twenty grains per hour, compared with a standard gas-burner containing five cubic feet per hour. When it is supposed to give fifteen times the amount of light furnished by such standard candle, the gas is said to have fifteen-candle power, or be fifteen-candle gas. But the standard of illuminating power can easily be raised by the addition of a few per cent. of some rich cannel or

oil shale, or some substance of the character of albertite or grahamite; for example, from a coal that produces by itself fifteen-candle gas, by the addition of ten per cent. of cannel the gas was raised to the standard of eighteen candles. Many coals which produce gas of a low illuminating standard, but in large quantities, and which coke well, are used as gas coals.

“3. It is important that the coal should contain but a small proportion of sulphur compound, as it is then easily purified, requiring less lime, producing a better quality of gas, and the coal may be safely stored without danger from spontaneous combustion. Good gas coal should not require more than one bushel of lime to purify five or six thousand feet of gas. The sulphur in coal is sometimes in combination with iron; in other cases it passes off in a volatile state, leaving but little in the coke. For gas-making this latter is a disadvantage, as the less sulphur entering the gases the better, since it must be removed by purification. For the blast furnace, on the contrary, the less sulphur remaining in the coke the better, since it is the sulphur in the coke which is injurious, and not that in the hydrocarbons, which pass off at the top of the furnace stack. In some cases, however, when the gas carries with it most of the sulphur, the gas may be so superior in illuminating power as to warrant its use, notwithstanding its increased cost of purification.

“4. A ton of good coal, used in the manufacture of gas, should produce thirty-five to forty bushels of coke, weighing thirty-five pounds to the bushel. The coke is

used for heating the retorts, and should burn up clean, with but little clinker. There should be a surplus of coke when a large amount of gas is manufactured, besides that used in the gas-house, and this is valuable to the gas manufacturer as a merchantable product, especially in localities where coal of a good quality for domestic and other purposes is expensive."

Non-caking Coals have the property of burning free in the fire much the same as wood charcoal burns—that is, heat does not cause them to fuse or run together in the fire. Perhaps the representative non-caking bituminous coal is the block coal of the western states, and noticeably, that of Indiana.

Block Coal—An analysis of this coal is given on page 56 and may be described as laminated in structure, consisting of successive layers of coal easily separated into thin horizontal slices not unlike slate; between these slices of coal is a layer of fibrous carbon resembling charcoal. In appearance it has a dull lusterless face on the line of separation, and glistening or resinous black when broken at right angles to its horizontal face. A peculiarity of this formation and that which gives it its name, is the presence of fractures occurring in the coal bed at right angles, or nearly so, and extending from top to bottom of the seam, enabling the miner to get it out in rectangular blocks as these lines of fracture indicate or permit.

It is a very strong coal and will burn well under a heavy load without crushing. The blocks are very com-

compact and will endure rough handling and stocking without suffering material loss from abrasion. This, in a commercial point of view, gives the block coal great value over and above its other good qualities as a fuel for smelting iron and generating steam.

Free-burning coal means the same as a non-caking coal.

CARBONIZATION OF COAL.

Coke is the residual product of the carbonization of bituminous coal. The only coke of any commercial value is that made from caking coals. When screenings and small particles, as well as ordinary small lumps of such coal, are heated sufficiently high and protected from the atmosphere (in a closed vessel, such as a retort used in gas-making, or, coke ovens, when manufactured on a large scale), the volatile portions of the coal are driven off, and a coherent mass of fixed carbon, containing usually five to ten per cent. of earthy matter, alone remain; this is called coke.

An analysis of the coal from which the celebrated Connellsville coke is made is given on page 57. This coke is very hard, occurs in long pieces not unlike ordinary stove wood, is of a steel grey color, having a bright metallic luster. It is used largely in the western states for the melting of iron in cupola furnaces, etc., and is a most excellent fuel for such purposes, requiring, however, a strong draft, judging by comparison, about the same as Lehigh anthracite coal; it yields an intense heat, burns free under a strong blast, and will support a

considerable weight of iron above it in the cupola without crushing.

The coke remaining after the distillation of coal in retorts, for the purpose of obtaining an illuminating gas, is known as *gas coke*. This is not so hard, is more easily ignited, and burns with a draft less intense than the preceding coke. This is a favorite fuel for domestic use, and burns well in steam boiler furnaces, or in any place where it is not subjected to any considerable pressure. Its power of resistance seems to be weakened by the manner in which it is coked, and the practice of cooling the charges drawn from the retorts by turning a stream of water on the incandescent coke while in contact with the atmosphere; but aside from this, the quality of coal selected for gas-making has much to do with it, the selection being made with reference to the quantity of gas it will yield rather than the quantity and quality of coke remaining after distillation.

THE INFLUENCE OF TEMPERATURE AND PRESSURE IN THE YIELD OF
COKE.

Temperature—The quality of coke is affected by the temperature at which it is made. In no case can coking occur at a temperature less than that at which coal suffers decomposition. Coking is not a mere fusing of coal into a mass; it is rather a process of distillation, in which all the volatile portions of the coal are separated from that solid portion called fixed carbon. This distillation can only occur at a high temperature, and observation shows that as a general rule the higher the temperature, and

the longer the exposure to that temperature, the harder, more dense, and less easily combustible will be the coke.

M. de Marsilly (20) tried the effect of coking during ninety-six, and one hundred and twenty hours, and found that no advantage was derived by prolonging the process beyond forty-eight hours.

Pressure—In order to test the effect of pressure on the quality of coke, experiments were made in the laboratory of Professor E. T. Cox, during which he was assisted by Dr. G. M. Levette. The following table gives the results of the experiments as determined by them:

TABLE X—COALS COKED UNDER DIFFERENT DEGREES OF PRESSURE.

NO.	PLATINUM CRUCIBLE, PROXIMATE ANALYSIS.	IRON RETORT.			
		NO MERCURY.	3 INCHES MERCURY.	6 INCHES MERCURY.	12 INCHES MERCURY.
1	52.40	59.10	62.00	62.80	59.40
2	52.50	54.35	54.00	54.30	56.50
3	55.50	56.10	56.40	57.95	56.15
4	57.50	58.85	60.40	58.50	59.25
5	58.50	62.20	61.75	62.60	63.40
6	57.90	65.05	65.00	65.10	66.10

NAME OF THE MINE OR OWNER.

- No. 1. H. K. Wilson's, Sullivan county, Indiana.
- No. 2. Simpson's, Knox county, Indiana.
- No. 3. Shepard & Haslett's, Knox county, Indiana.
- No. 4. Woodruff & Fletcher's, Clay county, Indiana.
- No. 5. Barnett's, Clay county, Indiana.
- No. 6. Stone's, Pittsburg, Pennsylvania.

Nos. 1, 2, 3 and 6 of the table are caking coals; Nos. 4 and 5 are non-caking or block coals.

The coke from No. 1 made in the retort, without pressure, was moderately firm, close textured, of grayish black color and without luster; with a pressure exerted by a column of water four inches high (not given in the table) the coke was not increased in weight, but appeared more compact and presented a radiated, crystalline structure, the rays run from a small central core to the circumference. This peculiar structure was lost when the pressure was increased. Up to a six inch pressure of mercury there was a gain of 3.7 per cent. of coke, which was very dense and strong. At twelve inches of pressure the per cent. of coke was scarcely more than that obtained without pressure, and gave signs of puffing. From this it will be seen that six inches of mercury gives the maximum per cent. of coke, and that beyond this the heat is sufficient to liquify the fixed carbon, and expand its particles so as to make a puffed, porous cake. There was little difference in the time occupied in coking, with or without pressure. The average time was forty-five minutes.

Instead of the coal being powdered, as was the case in the above experiment, some pieces a little larger than a pea were coked under six and twelve inches pressure, and they were found unchanged in shape except that the edges were slightly fused, and they were cemented together like a pop-corn ball. The color and appearance of the pieces resembled anthracite coal far more than coke. Under twelve inches pressure the pieces

were slightly swollen, but in color and structure otherwise presented the same appearance as the former.

Nos. 2 and 3, caking coals, gave a cellular coke without pressure, and the cells were only slightly enlarged by twelve inches of pressure. The weight of coke in No. 2, at twelve inches, was increased by four per cent., and that of No. 3 by only 0.65 per cent., while under six inches pressure the increase was 2.45 per cent.

Though these coals do not puff up, under pressure, as much as Nos. 1 and 6, the result clearly points out that all three belong to a class of coals that will not make a good coke under pressure, but that the coking oven, like the retorts at the gas works, should be subjected to a process of exhaustion.

No. 4 coked without pressure, and gave a coke that possessed but little cohesion; as the pressure increased the coke was more compact, and under twelve inches pressure it was strong and good; the color, like that of No. 1, resembled anthracite rather than coke; the greatest increase was produced by pressure of twelve inches, and only amounted to 1.75 per cent.

No. 5. This is one of the driest burning of the block coals and the particles were but slightly coherent even under a pressure of twelve inches; the increase in weight at this pressure amounted to 4.9 per cent.

The greatest pressure exerted on the block coals did not cause the carbon to become liquid as in the coking coals and the particles were simply cemented together by fusing on the surface. Lumps, when coked under

pressure, do not therefore swell, but rather become more dense and homogeneous with an increase of heat.

No. 6. The effect of pressure on this coal was quite different from that of No. 1, and equally as remarkable. The weight of the coke continued to increase up to a pressure of twelve inches, where it gained 8.2 per cent. over the result in the first column, but it was puffed up until the shape resembled a hen's egg and contained a large cavity in the center of the mass. The fracture presented also a cellular structure like a sponge. Without any pressure this coal gave a moderately dense coke but continued to puff up with every inch of pressure added.

It appears that, in order to make a homogeneous good coke, the fixed carbon of the coal must be of a kind that will melt at the lowest possible temperature, for if the process of coking produces the least pressure on the volatile hydrocarbons, whereby there is an increase of heat, such pressure causes so complete a liquefaction and expansion of the fixed carbon that the coke is left cellular instead of being compact. If such a coal is coked by covering it with an inch of sand and leaving the cover of the retort off, the coke will be dense and strong and without cells that are perceptible to the eye. On the other hand, coals, like the block coal of Indiana, which requires a very high temperature to meet its fixed carbon, does not have its fixed coke expanded by heat induced by an over-pressure of the eliminated gas, but as far as tried in the above experiments, the solidity of the block coal coke increased as the pressure was aug-

mented by raising the column of mercury through which the gas had to escape; such coals then are eminently adapted, in the raw state, for smelting iron in the blast furnace.

Mr. A. L. Steavenson read a paper before the Iron and Steel Institute, at Newcastle, England, on the manufacture of coke, in which he gives some interesting data in regard to coking coal. After giving a description of the furnaces employed in the particular manufactories to which he refers in the first part of his paper, he then goes on to say: "Two hundred and thirty tons of coal of the following approximate composition,

	TONS.
Oxygen.....	15.3
Carbon.....	195.3
Hydrogen.....	10.4
Nitrogen.....	2.3
Sulphur.....	1.4
Ash	5.3
	<hr/> 230.0

Yield, on coking, about sixty per cent. of coke, of the following approximate composition:

	TONS.
Carbon.....	132.7
Ash	5.3
	<hr/> 138.0

"Therefore, the composition and weight of the materials lost in coking are,

	TONS.
Carbon.....	62.6
Hydrogen.....	10.3
Nitrogen.....	2.3

Sulphur.....	1.4
Oxygen.....	15.3

To complete the combustion of these into N, CO₂ H₂ O and SO₂ are required 1023.4 tons of air, making a total weight of waste gases of 1115.4 tons, of which:

790.3 tons are nitrogen.

229.5 tons are carbonic acid.

92.8 tons are steam.

2.8 tons are sulphurous acid.

Which, at a temperature of fifteen hundred deg. Fahr., will occupy a space of one hundred and twenty-three million nine hundred and ninety-nine thousand cubic feet; and since the coking of two hundred and thirty tons of coal occupies, on an average, eighty-four hours, we have twenty-four thousand four hundred and ninety-three cubic feet per minute, or four thousand and five* cubic feet less than the observed quantity as above.

“Next, as to the heat commonly wasted. We have 1115.4 tons of mixed gases, at a temperature of fifteen hundred deg. Fahr., which, if they could be reduced to the temperature of the atmosphere (say sixty deg. Fahr.), we would have the following heating value in tons of H₂ O (water) raised one deg. Fahr.

	TEMPERATURE.				
	TONS.	DEGS.	SP. HEAT.	TONS H ₂ O.	
N.....	790.3	×	1440	×	.244 = 277,680
CO ₂	229.5	×	1440	×	.216 = 71,384
H ₂ O	92.8	×	1440	×	.475 = 63,477
SO ₂	2.8	×	1440	×	.155 = 625
Tons H ₂ O (water).....					413,166

* This four thousand and five cubic feet refers to some experiments at the kilns. B.

Which is equivalent to evaporating 415 tons of water at 212° Fahr. But owing to the fact that the temperature of the gases was only reduced 750° Fahr., instead of 1,440° Fahr., the above quantity is reduced to about one-half, or 216.1 tons, evaporated in eighty-four hours, or 2.6 tons in one hour. This was tested in an actual experiment (on the two boilers supplied with the gases from fifty ovens, coking the 230 tons in eighty-four hours), the quantity evaporated in one hour being 2.4 tons, an approximation quite as close as can be expected.

“The total theoretical heat actually developed in the process of coking at the above rate is equivalent to evaporating 17 tons of water per hour, which is thus expended:

	TONS.
Heat utilized by the boilers	2.40
Heat escaping in chimney	2.54
Heat lost in radiation from ovens and flues.....	12.06
	<hr/> 17.00

“Thus, even in the plan described, but a small percentage of the total heat generated in the ovens is utilized, although if this was carried out throughout the district of South Durham, where in colliery boilers not more than 6 lbs. of water, on the average, is evaporated per 1 lb. of coals, we should have a saving of 1,085,869 tons of coal per annum, or a money value of £271,467 (\$1,313,900.28).”

CANNEL COAL.

Cannel Coal is a variety of bituminous coal very rich in hydrogen. From the amount of combustible matter which it contains, and the readiness with which this is

given off in combustion, accounts for the name given it by the miners as *cannel*, a corruption of candle coal. This coal kindles readily, and burns without melting, emitting a bright flame like that of a candle. When thrown in the fire the piece splits up into fragments, producing a crackling noise which, from a fancied resemblance, has also received the name of *parrot* coal.

In appearance this coal differs from all other bituminous coals; its structure is more nearly homogeneous than others, being a compact mass, varying from brown to black in color, and having usually a dull resinous luster. When broken it does not usually preserve any distinct order of fracture, and is liable to split in any direction. On account of its being excessively rich in hydro-carbons it is highly esteemed as a gas-coal, preference being given to those coals in which hydrogen bears the greatest proportion to the contained oxygen.

ANALYSIS OF VARIOUS CANNEL COALS.

An analysis of cannel coal from near Franklin, Pa., by Professor W. R. Johnson, gave,

	PER CENT.
Fixed Carbon.....	40.13
Volatile matter.....	44.85
Earthy matter.....	15.02
	<hr/> 100.00

Cannel coal from Dorton's Branch, Cumberland river, Ky. Coal: close-textured, concentric-structured, brilliant, conchoidal. By Dr. D. D. Owen.

	PER CENT.
Fixed carbon.....	55.1
Volatile matter.....	42.9

Earthy matter	2
	<hr/>
	100.0

Specific gravity, 1.25.

Ashes, orange-colored.

Breckenridge, Ky., cannel coal. Proximate analysis
by Dr. Peters.

	PER CENT.
Carbon	32.00
Volatile matter.....	54.40
Moisture.....	1.30
Ash	12.30
	<hr/>
	100.00

This coal, by elementary analysis, gave,

	PER CENT.
Carbon.....	68.128
Hydrogen.....	6.489
Nitrogen.....	2.274
Oxygen and loss.....	5.833
Sulphur.....	2.476
Ash.....	14.800
	<hr/>
	100.000

Buckeye Cannel Coal Company, Davis county,
Indiana. By Professor E. T. Cox.

PROXIMATE ANALYSIS

	PER CENT.
Fixed carbon.....	42.00
Gas.....	48.50
Hydroscopic water.....	3.50
Ash, white.....	6.00
	<hr/>
	100.00

Coke—is laminated, not swollen, lusterless.

Specific gravity, 1.229.

One cubic foot weighs..... 76.87 lbs.

ULTIMATE ANALYSIS OF THE SAME.

	PER CENT.
Carbon.....	71.10
Hydrogen	6.06
Oxygen.....	12.74
Nitrogen.....	1.45
Sulphur	1.00
Ash.....	7.65
	<hr/> 100.00

The heat units in this coal are thirteen thousand one hundred and thirty-one, thus:

$$.7110 \text{ carbon} \times 14,544 = 10,340 \text{ carbon heat units.}$$

$$.045 \text{ available hydrogen} \times 62,032 = 2,791 \text{ hydrogen heat units.}$$

$$10,340 \text{ carbon heat units.}$$

$$2,791 \text{ hydrogen heat units.}$$

$$13,131 \text{ total heat units in the coal.}$$

SEMI-BITUMINOUS COAL.

Semi-bituminous Coal is not so hard, and contains more volatile matter than true anthracite. In this, as in all other classification of coals, its limits must be somewhat arbitrarily fixed. In appearance it more closely resembles the anthracite than the bituminous coals, differing from the former: in fracture, as being less conchoidal; it is not so hard; is of a less specific gravity; and when thrown upon the fire it kindles much more readily and burns faster than anthracite. It takes high rank as a fuel; although, containing less carbon than anthracite, it is quite as desirable on account of the readiness with which it kindles, and the quantity of heat it is capable of giving off when burned

in steam boiler furnaces, and in stoves for domestic use. It is much more easily regulated in burning than anthracite, and is almost entirely free from the smoke and soot of ordinary bituminous coal.

Analysis of semi-bituminous coal from *Cumberland*, Maryland. By Professor W. R. Johnson.

Specific gravity, 1.41.

	PER CENT.
Fixed carbon.....	68.44
Volatile matter.....	17.28
Earthy matter.....	13.98
Sulphur.....	.71
	<hr/> 100.41

Blossburg, Pennsylvania, from Geological Survey of Pennsylvania.

Specific gravity, 1.32.

	PER CENT.
Fixed carbon.....	73.11
Volatile matter.....	15.27
Earthy matter.....	10.77
Sulphur.....	.85
	<hr/> 100.00

The heat units in this coal determined as below are thirteen thousand one hundred and fifty-five:

Carbon.....	$.7311 \times 14,544 =$	.....	10,633
Volatile matter.....	$.1527 \times 20,115 =$	3,072	
Less.....	$.1527 \times 3,600 =$	550	2,522
Total heat units.....			<hr/> 13,155

SEMI-ANTHRACITE COAL.

The semi-anthracite coals are restricted, with few exceptions, to those coals which possess on an average

from seven to eight per cent. of volatile combustible matter. In consequence of this element, part of which, at least, resides probably in a free or gaseous state in the cells or clefts of the coal, this variety kindles more promptly, and, when sufficiently supplied with air, burns more rapidly than the hard anthracite.

Wilkesbarre, Pennsylvania, semi-anthracite, described as compact, conchoidal, iron-black, splendant. Geological survey of Pennsylvania.

Specific gravity, 1.40.

	PER CENT.
Fixed carbon.....	88.90
Volatile matter.....	7.68
Earthy matter.....	3.49
	<hr/> 100.07

Neglecting the .07 we have in this coal 14,199 units of heat, thus—

Carbon.....	$.8890 \times 14,544 =$	.....	12,930
Volatile matter.....	$.0768 \times 20,115 =$	1,545	
Less.....	$.0768 \times 3,600 =$	276	1,269
			<hr/> 14,199

ANTHRACITE COAL.

True anthracite, when pure, is slow to ignite, conducts heat very badly, burns at a very high temperature, radiates an intense warmth, and is difficult to quench. Generating almost no water during its combustion, it powerfully dessicates the atmosphere of an apartment in which it is burning.

It consists, when pure, (23) of

Carbon.....	from 90 to 94 per cent.
Hydrogen.....	from 1 to 3 per cent.



Oxygen and nitrogen.....	from 1 to 3 per cent.
Water.....	from 1 to 2 per cent.
Ashes.....	from 3 to 4 per cent.

The constituents which vary most are, of course, the carbon and earthy matter.

Hard anthracite, from its great richness in carbon and its density, stands at the head of all coals for its heat generating power, if adequately supplied with air. It is the most economic of all fuels—weight for weight—for smelting and melting iron and the other metals.

The superior density of hard anthracite over every other kind of coal, by lessening the room demanded for stowage, gives it a decided preference in this respect as a fuel for ocean steamers.

In burning it neither softens nor swells, and does not give off smoke; the flame is quite short, and has a yellowish tinge when first thrown upon the fire, which soon changes to a faint blue, with occasionally a red tinge. The flame being quite short and free from particles of solid carbon, has the appearance of being transparent.

When broken it presents a conchoidal appearance, and appears quite homogeneous in structure. It will stand weathering and stowage better than other coals.

ANALYSIS OF ANTHRACITE COAL FROM TAMAQUA, PENNSYLVANIA.

GEOLOGICAL SURVEY OF PENNSYLVANIA.

This coal is described as compact, slaty, conchoidal, greyish black, splendant.

Specific gravity, 1.57.

	PER CENT.
Fixed carbon.....	92.07
Volatile matter.....	5.03
Earthy matter.....	2.90
	<hr/>
	100.00
Ashes, white.	
Units of heat in 1 pound of coal.....	14,221

Beaver Meadow (Pa.) Anthracite. Prof. W. R. Johnson.

Specific gravity, 1.55

	PER CENT.
Fixed carbon	90.20
Volatile matter.....	2.52
Earthy matter.....	6.13
	<hr/>
	98.85

No explanation is given by Professor Johnson for the 1.15 per cent. loss not accounted for in the analysis, but neglecting this, we have 13,535 units as the calorific power of this coal, determined as follows:

Carbon.....	$.9020 \times 14,544 =$	13,119
Volatile matter.....	$.0252 \times 20,115 =$	507
Less	$.0252 \times 3600 =$	91 =
		<hr/>
Total heat units.....		13,535

CHAPTER IV.

ANALYSIS OF COAL.

Analysis, Chemical, Qualitative, Quantitative, Proximate—Selection of Samples for Analysis—Method of Conducting a Proximate Analysis—Elementary Analysis—Determination of Sulphur and Phosphorus—Carbon—Hydrogen—Carbureted Hydrogen—Sulphur—Products obtained from Coal.

Analysis—The separation of a body into its constituent elements is called *chemical* analysis; when it is desired to know simply what elements compose a body it is known as *qualitative* analysis; when the quantity of each element is to be determined it is then known as *quantitative* analysis. When, as in the ordinary analysis of coal, it is desirable to determine what percentage of volatile matter, fixed carbon, and ash, are contained in a given sample, this process is known as *proximate* analysis, and simply informs as to the physical peculiarities of the coal and not as to its elementary composition.

The elementary analysis of coal shows it to be principally composed of the following simple substances:

Carbon;	Oxygen;
Hydrogen;	Sulphur; and
Nitrogen;	Ash.

Ash is not a simple substance, but represents the incombustible matter of whatever composition remaining in the furnace after combustion.

By proximate analysis the coal would be said to contain

Fixed carbon;	Moisture or water;
Volatile matter;	Ash.

In the analysis of coal it is desirable to know,

1. The percentage of volatile matter it contains.
2. The percentage of fixed carbon.
3. The percentage of earthy matter, or the presence of such bodies as do not contribute to its heating value.

This can only be arrived at by a process of destructive distillation.

Professor E. T. Cox, State Geologist of Indiana, has given the analysis of coals particular attention. His suggestions in regard to samples, and his method of conducting analysis, whether proximate or elementary, are given below; also, his method of determining the amount of sulphur, phosphorus, iron and alumina in coal.

Samples—It is a matter of no little difficulty to select from a mine a proper sample for analysis, at least such a sample as will represent the average commercial value of the seam. The best way, therefore, is to take a sample from the top, middle and bottom of the seam. These should be carefully labeled, wrapped in paper and sent to the laboratory as soon thereafter as practicable. On arriving at the laboratory they should be taken in hand at once. About a pound of each sample should be pulverized fine enough to be passed through a porcelain colander with one-tenth inch perforations; then transferred to bottles with good cork stoppers. Each bottle should be labeled, showing the date of mining, when bottled, name of mine, etc. These bottles serve

as stocks from which the different quantities are to be taken that serve for analysis. It is not a good plan to mix the portions taken from different parts of the seam and consider the mixture an average sample, so that one set of analysis may serve; for though it might furnish a fair statement of the commercial value of the seam, it would leave us in ignorance of much useful information in regard to the true character of the seam.

PROXIMATE ANALYSIS.

One *gram* is charred in a covered platinum crucible of about one fluid ounce capacity. The heat is derived from a three-jet Bunsen gas burner, and the crucible kept at a bright red heat until the escaping gas ceases to burn and the condensed carbon disappears from the cover. The weight of the charred mass gives the coke, and the volatile matter is estimated by the loss. To determine the hygroscopic water, one *decigram* of pulverized coal is weighed in a small, shallow platinum capsule and placed in a hot-air bath, where it remains at a temperature of 100 to 105 deg. Cent. for one hour; the loss gives the water. The capsule, with the dry coal, is then placed over a strong flame of a Bunsen burner until it is consumed to ash.

The weight of the ash is deducted from the coke to find the fixed carbon, and the weight of the water is deducted from the volatile matter to find the per cent. of combustible gas.

All this appears very simple, but it requires great care and attention to obtain reliable results. The tem-

perature of 100° C (212 Fahr.) is recommended, since it is believed that a higher temperature is no more effective and is more liable to produce decomposition of the volatile constituents.

ELEMENTARY ANALYSIS.

The combustion is best performed in a hard glass tube, twenty inches long and three-quarters of an inch in diameter.

Twelve inches of the posterior end is filled with a tightly-rolled coil of fine copper gauze. This is oxidized by drawing air through the red-hot tube with an aspirator. The usual appliances are used to dry the oxygen and free it from carbonic acid and other impurities, and also arrest the hydrogen, sulphur and carbonic acid.

Previous to commencing the combustion, a current of pure oxygen is passed through the heated tube to complete the oxidation of the copper and expel the last trace of moisture. Two *decigrams* of pulverized coal are now placed in a platinum boat and inserted in the anterior part of the tube, about three inches from the copper. The heat of the gas furnace is applied with due precaution, and the combustion is completed when the coal has been burnt to ash and oxygen bubbles pass freely through the potash apparatus. When the hydrogen, sulphur, potash apparatus and potash **U** tube have been weighed, another analysis may be proceeded with, and in this way as many as four combustions may be made in a day. A good tube will serve for ten or twenty combustions. The potash apparatus should be

renewed after every third combustion, in order to insure a proper absorption of the carbonic acid.

The advantages to be derived from this mode of conducting the analysis, are: You are enabled to watch the combustion of the coal and see when it is completed; the ash may be determined at the same time and the tube is at once ready for the reception of another sample of coal. Nitrogen is determined by Varrentrapp and Will's method, *i. e.*, by conversion into ammonia. The ammonia is received in a measured quantity of standard oxalic acid, and the amount of free acid remaining is determined by neutralizing with a standard solution of soda. The quantity of acid saturated by ammonia is then found from the difference.

DETERMINATION OF SULPHUR AND PHOSPHORUS.

There is, generally speaking, less reliance to be placed in published statements of the amount of sulphur and phosphorus in coals than in any one of its other elementary constituents.

The results are, as is well known, generally under rather than over the actual amount of sulphur present in coal.

The loss is due to a portion of the sulphur being converted into sulphureted hydrogen and the phosphorus into phosphureted hydrogen, which escapes during the process of dissolving the coal. In order to avoid this loss, five *decigrams* of coal are fused with eight grains of caustic potash and two grains nitrate of potash, in a silver crucible.

Both the caustic potash and nitrate of potash should be tested for sulphur and the per cent. marked upon the bottle. The half *gram* of powdered coal is placed in the crucible and moistened with alcohol, eight *grams* of potash are then put in with the coal and placed over a moderate heat until the potash is melted, after which two *grams* nitrate of potash are added, the whole is kept at a gentle heat for about two hours or until all the moisture is expelled; the heat is then increased until all ebullition ceases. The coal should dissolve without deflagration from ignition. After cooling, the contents of the crucible are dissolved out with water and neutralized with hydrochloric acid, evaporated to dryness, moistened with hydrochloric acid and re-dissolved with water. Filter out the silicic acid, heat the filtrate and precipitate the iron and alumina with ammonia and determine the sulphuric acid in the filtrate with chloride of barium.

The phosphoric acid is precipitated with the iron, and to separate it, the precipitate is dissolved from the filter with a weak solution of hydrochloric acid, and then evaporated to dryness to separate the last trace of silicic acid.

Moisten with nitric acid, dissolve in water, filter and precipitate the phosphoric acid with molybdate of ammonia. Wash the precipitate as directed by Fresenius, dissolve with ammonia and precipitate phosphoric acid with sulphate of magnesia. In order to determine the per cent. of iron and alumina, it is better to take another half *gram* of coal and fuse as before. The iron

and alumina are then precipitated from the hot solution with ammonia, and the alumina is separated by digesting the precipitate with hydrate of potash in a silver crucible.

This mode of determining the sulphur, phosphorus, iron and alumina in coal, is simple, expeditious and accurate. It has been adopted after repeated trials of all other known processes, and leaves nothing to be desired.

CARBON AND HYDROGEN.

CARBON—(*Symbol C; atomic weight 12*). This is one of the most widely diffused and abundant of the elements. It exists in several *allotropic* states; that is, it exists in several conditions, each having different physical properties, whilst its chemical properties remain unchanged.

The commonest forms in which pure carbon occurs are the diamond, black lead and charcoal. We can scarcely imagine three solids more unlike in their physical properties than these, yet chemically, they are the same thing; that is, they yield upon analysis nothing but carbon. It is the principal constituent of anthracite coal; it constitutes about one-half of bituminous coal; and is an essential element in organic bodies, from which it may be separated in the form of charcoal, by distilling off the more volatile elements.

Carbon unites directly with oxygen, sulphur, nitrogen, and a few of the metals, the latter at high temperatures only. The two direct inorganic compounds of carbon and oxygen are known as carbonic oxide and

carbonic acid; the proportions are shown in the following table:

TABLE XI.

	SYMBOL.	COMPOSITION.					
		BY WEIGHT.			PERCENTAGE.		
		CARBON.	OXYGEN.	TOTAL.	CARBON.	OXYGEN.	TOTAL.
Carbonic Oxide..	C O	12	16	28	42.86	57.14	100
Carbonic Acid....	C O ₂	12	32	44	27.27	72.73	100

These are the two principal gases formed in the furnace by the combustion of the carbonaceous portions of the fuel. The table of products obtained from coal (page 94) show about fifty different combinations of carbon with different elements and in different proportions.

Almost all the elementary substances of which the specific heat and atomic weight are known, give, when these two properties are multiplied into each other, a product approximating an average of 6.34. Carbon is one of the exceptions to this rule, as the following will show:

	SPECIFIC HEAT.	ATOMIC WEIGHT.	PRODUCTS.
Carbon (diamond).....	0.1469	12	1.76
Carbon (graphite).....	0.2008	12	2.41
Carbon (wood charcoal).....	0.2415	12	2.90

The other two exceptions are boron and silicon. Carbon is quite remarkable for the differences in its physical conditions, and this is sometimes brought forward as a partial reason for the low product shown in

the above table. There is no doubt this fact has much to do with it, but is not a very satisfactory way of disposing of so marked a difference in an element so widely diffused, and so generally employed in manufactures and domestic use.

HYDROGEN—(*symbol H; atomic weight 1*), is the lightest substance known. When pure it is colorless, tasteless, and inodorous. It is one of the few substances known to us only in the gaseous state. The theory that hydrogen is the vapor of a metal was proposed by the French chemist, Dumas, about forty-nine years ago (1830?), but from our knowledge of the gas we can scarcely imagine it to be solidified except by the withdrawal of heat until no more can be extracted, or, until absolute zero (461 deg. below the zero of Fahr.) is reached, when, of course, hydrogen would cease to exist as a gas, and would become inert or assume a solid state, and would so remain until a rise in temperature would permit molecular motion, and so restore it to its gaseous form. Many experiments have been made to reduce it, if possible, to a liquid state. In the *Scientific American*, February 23, 1878, is an engraving of the apparatus employed by M. Cailletet, of Paris, in his experiments, during which he succeeded in liquefying hydrogen. It is said that M. Raoul Pictet has not only succeeded in obtaining liquefied hydrogen, but also solidified it at Geneva, January 10, 1878.

Hydrogen is not found in a free state, though it is an essential element in all organic substances, from which it may be separated by a process of destructive

distillation. It occurs in nature in combination with carbon; the compound which contains it in greatest abundance is marsh-gas, of which hydrogen forms one-fourth, the formula being CH_4 . This same gas often occurs in mines, where it is known as fire-damp.

Under ordinary temperatures and at ordinary pressures hydrogen has no tendency to enter into combination with other substances. It combines with eight parts of oxygen to form water, but this combination does not take place spontaneously. The two gases will remain together as a mere mechanical mixture any length of time; upon the application of a spark, however, the chemical union of the two gases is instantaneous and violent. Liquid water contains 1238 times its volume of free gaseous hydrogen, and when we consider the oceans of water throughout the world and the volume of hydrogen required to form this water, it makes a quantity which, expressed by ordinary measurements, is almost beyond comprehension.

Pure hydrogen burns in the atmosphere with a pale blue light, scarcely perceptible in full daylight, giving off an intense heat. Favre and Silberman ascertained the heat of one pound of hydrogen burned in oxygen to be sufficient to raise the temperature of 62,032 pounds of water one degree Fahr. This is not equalled by any other known substance.

Carbureted hydrogen has long been employed as an illuminating agent, and has been obtained by the distillation of the volatile portions of bituminous coal, yield-

ing a hydro-carbon gas of the following approximate composition :

Hydrogen.....	41.85
Marsh-gas.....	39.11
Carbonic oxide.....	5.86
Olefines.....	7.95
Nitrogen.....	5.01
Carbonic acid.....	.22
	<hr/>
	100.00

This composition will vary, of course, in different sections of the country, owing to different coals employed, and care in manufacture. The production of hydro-carbon gases on a large scale for illuminating purposes has engaged the minds of inventors not only, but has profitably employed vast sums of money in this great and almost indispensable industry. Within a few years past the possibility of economically decomposing water in order to utilize its hydrogen as an illuminating agent has been fully demonstrated on a large scale, and it appears as if, in addition to its employment as an illuminating agent, it, at no very distant day, by virtue of its extraordinary and unparalleled heating power, is destined to supercede our present wasteful method of heating city homes, mercantile and manufacturing buildings, etc., promising at once a heat in any desired quantity, easily controlled, with perfect cleanliness, and more economical in many cases than crude fuel.

Hydrogen unites with nitrogen to form ammonia, the formula being NH_3 .

SULPHUR—(*symbol S; atomic weight 32*), is often found in coal in combination with iron, and is known as iron pyrites. Some specimens are of great beauty, but underneath this attractive exterior lurks a dangerous enemy to steam boilers. Sulphur is highly inflammable, and when heated in the air to a temperature of about 482° Fahr. it takes fire and burns with a clear blue, feebly luminous flame, being converted into sulphurous oxide, SO_2 . In its chemical relations sulphur is the representative of oxygen, to which it is equivalent, atom to atom. Oxygen gas and sulphur vapor alike support the combustion of hydrogen, charcoal, phosphorus, and the metals to form precisely analogous compounds.

“The presence of sulphur in common coal gas has received considerable attention, from a sanitary point of view, by gas chemists, who are somewhat divided in their opinions as to the precise state in which sulphur is introduced into the air. Mr. Thomas Wills, F. C. S., in a lecture delivered before the British Association of Gas Managers (1878), gives as his opinion that “The sulphur is first of all burnt to sulphurous acid, that then a certain portion of this sulphurous acid is oxidized into sulphuric acid, and that the amount so oxidized depends upon circumstances; but that given a sufficient length of time, the whole of the sulphurous acid will be oxidized into sulphuric acid. Now as to the circumstances: If the sulphurous acid is kept hot in the presence of moisture, then oxidization goes on more rapidly; if it be cooled down almost immediately after it is formed, the action is very slow, and within any

reasonable time it will be found impossible to entirely oxidize the whole of the sulphurous acid into sulphuric acid. Then, secondly, if the sulphurous acid meets with a base or with an easily-oxidizable substance with which it can unite, it undergoes oxidation much more readily than if it remains in a state of free acid.

“From my own experiments, I believe that under ordinary circumstances, considerably less than one-half of the sulphurous acid produced by the combustion of coal gas is oxidized in any reasonable time into sulphuric acid, and in this I am supported by several gentlemen, who not being connected with the coal gas industry, are, nevertheless, thoroughly acquainted with the behavior of sulphurous acid when used in the manufacture of alkali.”

Mr. Wills also makes the startling statement, in the same lecture, that if we regard the amount of coal burnt in London as eight million tons per annum, and we take that coal to contain one per cent. of sulphur which is burnt—whether in the form in which it is sent into the houses in gas, or in furnaces, or in grates, it is burnt in some way—and which is a low average, we shall have eighty thousand tons of sulphur thrown into the air in the form of sulphurous acid, and if that is calculated into oil of vitriol, it will amount, in one year, to two hundred and forty thousand tons of oil of vitriol sent into the atmosphere of London alone by the combustion of coal.

Though the amount of sulphur in the aggregate appears very large from the figures in the above para-

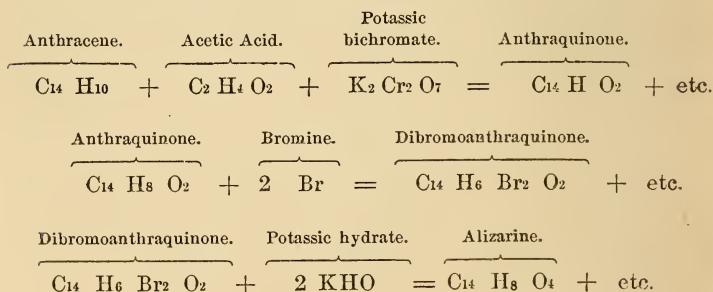
graph, it is not too large for the atmosphere to fully take care of it without detriment to health or comfort, but what concerns us chiefly in our present line of inquiry is, the effect of sulphur in coal upon steam boilers. The corrosive action of sulphur compounds on iron will be found in Chapter VIII.

PRODUCTS OBTAINED FROM COAL.

BY HENRY A. MOTT, JR.

Coal.	$\left\{ \begin{array}{l} \text{Gas, illum-} \\ \text{inating, etc.} \\ \text{Tar.....} \\ \text{Ammonia....} \\ \text{Water.....} \\ \text{Coke for} \\ \text{fuel.....} \end{array} \right\}$	$\left\{ \begin{array}{l} \text{Oils, 30} \\ \text{per ct.} \end{array} \right\}$	$\left\{ \begin{array}{l} \text{Naphtha} \\ \\ \\ \text{Dead Oil} \end{array} \right\}$	$\left\{ \begin{array}{l} \text{Benzole.....} \\ \text{Naphtha.....} \\ \text{Xylole.....} \end{array} \right\}$	$\left\{ \begin{array}{l} \text{Benzole.} \\ \text{Toluol...} \end{array} \right\}$	$\left\{ \begin{array}{l} \text{Used to} \\ \text{make} \\ \text{Aniline.} \end{array} \right\}$
				$\left\{ \begin{array}{l} \text{Benzole.....} \\ \text{Naphtha.....} \\ \text{Xylole.....} \end{array} \right\}$	$\left\{ \begin{array}{l} \text{Benzole.} \\ \text{Toluol...} \end{array} \right\}$	$\left\{ \begin{array}{l} \text{Used to} \\ \text{make} \\ \text{Aniline.} \end{array} \right\}$
				$\left\{ \begin{array}{l} \text{Benzole.....} \\ \text{Naphtha.....} \\ \text{Xylole.....} \end{array} \right\}$	$\left\{ \begin{array}{l} \text{Benzole.} \\ \text{Toluol...} \end{array} \right\}$	$\left\{ \begin{array}{l} \text{Used to} \\ \text{make} \\ \text{Aniline.} \end{array} \right\}$
				$\left\{ \begin{array}{l} \text{Benzole.....} \\ \text{Naphtha.....} \\ \text{Xylole.....} \end{array} \right\}$	$\left\{ \begin{array}{l} \text{Benzole.} \\ \text{Toluol...} \end{array} \right\}$	$\left\{ \begin{array}{l} \text{Used to} \\ \text{make} \\ \text{Aniline.} \end{array} \right\}$
				FURNISHES		
				$\left\{ \begin{array}{l} \text{Carbolic Acid} \\ \text{Cresylic Acid.} \end{array} \right\}$	$\left\{ \begin{array}{l} \text{Used for Disin-} \\ \text{fectants.} \end{array} \right\}$	
				$\left\{ \begin{array}{l} \text{Naphthalene.....} \\ \text{Anthracene, } \frac{1}{2} \text{ per ct.} \end{array} \right\}$	$\left\{ \begin{array}{l} \text{Dyes, etc.} \\ \text{Used to make} \end{array} \right\}$	
				$\left\{ \begin{array}{l} \text{Chrysene.....} \\ \text{Anthracene, 2 per cent.} \end{array} \right\}$	$\left\{ \begin{array}{l} \text{Alizarine.} \end{array} \right\}$	
		$\left\{ \begin{array}{l} \text{Pitch, 70} \\ \text{per ct.} \end{array} \right\}$	$\left\{ \begin{array}{l} \text{Used for Roofing and Pavements.} \\ \text{Anthracene, 2 per cent.} \end{array} \right\}$			

The preparation of alizarine from anthracene:



The following table gives a list of the products obtained by the distillation of coal:

NAME.	FORMULA.	GAS OR VAPOR. SPECIFIC GRAVITY.	BOILING POINT. DEGREES. CENTIGRADE.
Atmospheric air.....	.....	1.000	.....
Hydrogen.....	H	0.069	.....
Nitrogen.....	N	0.971	.....
Oxygen.....	O	1.106	.....
Ammonia.....	N H ₃	0.590	33
Aqueous vapor.....	H ₂ O	0.622	100
Carbonic oxide.....	C O	0.967	.....
Carbonic anhydride.....	C O ₂	1.529	109 (Fahr.)
Cyanogen.....	C N	1.801	.....
Sulphurous anhydride.	S O ₂	2.2112	+13.09 (Fahr.)
Carbon disulphide.....	C S ₂	2.645	47
MARSH GAS SERIES.			
Methyl hydride.....	C H ₄	0.5596	.....
Ethyl hydride.....	C ₂ H ₆	1.037	.....
Propyl hydride.....	C ₃ H ₈	1.522	.....
Butyl hydride.....	C ₄ H ₁₀	2.005	9
Amyl hydride.....	C ₅ H ₁₂	2.489	30
Hexyl hydride.....	C ₆ H ₁₄	0.669	65
Octyl hydride.....	C ₈ H ₁₈	0.726	108
Decyl hydride.....	C ₁₀ H ₂₂	.....	158
OLEFIANT GAS SERIES.			
Methylene.....	C H ₂	0.484	39
Ethylene (olefiant gas)	C ₂ H ₄	0.9784	.....
Propylene (tritylene)...	C ₃ H ₆	1.452	—17.8
Butylene.....	C ₄ H ₈	1.936	+35
Amylene.....	C ₅ H ₁₀	2.419	55
Caproylene (hexylene)	C ₆ H ₁₂	2.97	61.3
Enanthylene.....	C ₇ H ₁₄	3.320	99

NAME.	FORMULA.	GAS OR VAPOR. SPECIFIC GRAVITY.	BOILING POINT. DEGREES. CENTIGRADE.
ACIDS.			
Hydrosulphocyanic.....	$\text{H}(\text{C N})\text{S}$	.....	85
Hydrosulphuric.....	H_2S	1.175	.....
Carbolic (phenol).....	$\text{H}(\text{C}_6\text{H}_5)\text{O}$	1.065 (solid). *	188
Rosolic.....	$\text{C}_{20}\text{H}_6\text{O}_3$	.....	.....
Brunolic.....	.....	.....	.....
Hydrocyanic.....	H C N	0.7058	26.5
Acetic.....	$\text{C}_2\text{H}_4\text{O}_2$	2.079	120
ALCOHOLS.			
Cresylic alcohol.....	$\text{C}_7\text{H}_8\text{O}$	.....	203
Phlorylic alcohol.....	$\text{C}_8\text{H}_{10}\text{O}$	.....	.....
BENZOLE SERIES.			
Benzole.....	C_6H_6	2.695	82
Toluole.....	C_7H_8	3.179	111
Xylole.....	C_8H_{10}	3.179	129
Cumole.....	C_9H_{12}	4.147	148
Cymole.....	$\text{C}_{10}\text{H}_{14}$	4.632	175
Naphthalene.....	C_{10}H_8	4.423	212
Anthracene.....	$\text{C}_{14}\text{H}_{10}$	6.741	Melts at 213
Chrysene.....	C_6H_4	.....	.....
Pyrene.....	C_{15}H_4	.....	.....
		Sp.Gr. $\text{H}_2\text{O}=1$	
Aniline.....	$\text{H}_2(\text{C}_6\text{H}_5)\text{N}$	1.020	182
Pyridine.....	$(\text{C}_5\text{A}_5)\text{N}$	.....	115
Picoline.....	$(\text{C}_6\text{H}_7)\text{N}$	.09613	134
Lutidine.....	$(\text{C}_7\text{H}_9)\text{N}$	.921	154
Collidine.....	$(\text{C}_8\text{H}_{11})\text{N}$	.....	170
Parvoline.....	$(\text{C}_9\text{H}_{13})\text{N}$	.....	188
Coridine.....	$(\text{C}_{10}\text{H}_{15})\text{N}$	.....	211
Rudidine.....	$(\text{C}_{11}\text{H}_{17})\text{N}$	.....	230

NAME.	FORMULA.	GAS OR VAPOR. SPECIFIC GRAVITY.	BOILING POINT. DEGREES. CENTIGRADE.
Viridine.....	$(C_{12}H_9)N$	1.017	251
Lecoline.....	$(C_9H_7)N$	.....	235
Lepidine.....	$(C_{10}H_9)N$	.....	260
Cryptidine.....	$(C_{11}H_{11})N$	.....	256
Pyrrol.....	$(C_4H_5)N$	.....	133

CHAPTER V.

COMBUSTION.

Chemical Attraction—Muriate of Zinc—Gunpowder—Physical Changes—Chemical Changes—Definite Proportions—Multiple Proportions—Carbonic Acid—Carbonic Oxide—Law of Equivalents—Energy of Chemical Separation—Nature of Combustion—Conditions Necessary to Combustion—Luminosity—Ignition—Flame—Recent Studies of Luminous Flames—Rate of Combustion—Temperature of Fire—Weight and Specific Heat of the Products of Combustion—Available Heat of Combustion—Efficiency of a Furnace.

COMBUSTION—This term is given to those chemical combinations in which there is a rapid union of an element such as carbon, or hydrogen, with another element—for which it has the particular chemical attraction known as affinity—oxygen, for example; this combination resulting always in the formation of a new compound which does not have the properties of the elements of which it is composed. This union is generally accompanied by an evolution of light, and always of heat.

Oxygen is the great supporter of combustion and the chemical reactions of atmospheric air are due to the presence of this gas in its composition; the nitrogen present being inert or passive.

Chemical Attraction—This force is distinguished from other kinds which act within minute distances, by the complete change of characters which follows its exertion, and must, from its very nature, be exerted between

dissimilar substances. A good illustration of chemical attraction, and one well known to machinists, is that of dissolving zinc in muriatic acid to make a soldering liquid; atom by atom it yields to the action of the acid until the zinc entirely disappears; as a result there remains a liquid having neither the properties of the acid nor the zinc—a new compound has been formed.

A striking illustration of the difference between the effects of mechanical intermixture and those of chemical combination is afforded in the case of ordinary gun powder. (17). In the manufacture of this substance, the materials of which it is made—viz, charcoal, sulphur and nitre—are separately reduced to a state of fine powder; they are then intimately mixed, moistened with water, and thoroughly incorporated by grinding for some hours under edge stones; the resulting mass is subjected to intense pressure, and the cakes so obtained, after being broken up and reduced to grains, furnish the gun powder of commerce.

In this state it is a simple mixture of nitre, charcoal and sulphur. Water will wash out the nitre, bisulphide of carbon will take up the sulphur, and the charcoal will be left undissolved. By evaporating the water, the nitre is obtained; and on allowing the bisulphide of carbon to volatilize, the sulphur remains. If, however, we cause the materials to enter into chemical combination, all is changed; a spark fires the powder; the dormant chemical attractions are called into operation; a large volume of gaseous matter is produced; the char-

coal disappears, and no trace of the original ingredients which formed the powder is left.

The physical and other changes brought about by the formation of new compounds—a result of chemical attraction—do not destroy the combining elements, but simply re-arranges them in another form, and gives to the new compound properties not held by any element singly.

It means transformation, not destruction; no matter how much the substances may change their form, the weight of the new products, if collected and examined, will be found to be exactly equal to that of the substances before the combination. For example: the complete combustion of hydrogen and oxygen forms water, having properties entirely different from either of the two gases. Water may be decomposed, and resolved into the two gases of which it was formed. The weights, combined or singly, will in either case be the same.

Whenever substances unite directly with each other, heat is emitted, and varies with the nature of the substances between which it is exerted. In general, the greater the difference in the properties of the two bodies, the more intense is their tendency to mutual chemical action; on the other hand, the chemical attraction between bodies having properties closely allied to each other is less violent, and graduates so imperceptibly into mere mechanical mixture, that it is often impossible to mark the limit.

Definite Proportions—The law of definite proportions may be stated as follows (17):

In any chemical compound the nature and the proportions of its constituent elements are fixed, definite and invariable. For instance, 100 parts of water by weight contain 88.9 of oxygen and 11.1 of hydrogen; these gases will combine in no other proportions to form water, and any excess of either gas will remain unchanged.

When two or more compounds are formed of the same elements, there is no gradual blending of one into the other, as in the case of mixtures, but each compound is sharply defined and exhibits properties distinct from those of the others, and of the elements of which the compounds are composed. This is the principle in the law of *multiple proportions*.

There are two compounds of carbon and oxygen commonly known as carbonic acid (CO_2), and carbonic oxide (CO). They may be tabulated, in order to illustrate what has just been said in regard to multiple proportions, thus :

	SYMBOL.	CARBON.	OXYGEN.
		PARTS BY WEIGHT.	PARTS BY WEIGHT.
Carbonic oxide.	CO	12	16
Carbonic acid....	CO_2	12	32

It will be observed that, the quantity of carbon remaining the same, the quantity of oxygen must be doubled in order to form the other compound, carbonic

acid. These proportions constitute the only two direct inorganic compounds of carbon and oxygen. It is usual, in tabulating proportions, to give percentages of the composition instead of atomic weights; transposing the above, it would appear thus:

	SYMBOL.	ATOMIC WEIGHT.	CARBON.	OXYGEN.
Carbonic oxide....	CO	28	42.86	57.14
Carbonic acid.....	CO ₂	44	27.27	72.73

For an extended series illustrating the law of definite proportions of two of the constituents of coal gas, carbon and hydrogen, note the many combining proportions in the marsh gas, the olefiant gas, and the benzole series, of the products obtained from coal, given on page 95.

The whole table is one of great interest and value in connection with the study of the law of definite or multiple proportions, as well as a most valuable contribution to the chemistry of coal.

Law of Equivalents—By this is understood: if a body—oxygen, for example—unites with certain other bodies, hydrogen, carbon, nitrogen, sulphur, etc., then the quantities by weight in which the latter substances will combine with the oxygen, or contain multiples of these quantities, they represent in general the proportions in which they can unite amongst themselves.

Hydrogen combines with oxygen in a smaller proportion than any other known substance, and the numbers representing the equivalents of all other bodies may, for

practical purposes, be taken without material error, as multiples by whole numbers of the equivalent of hydrogen (17).

TABLE XIII.

TABLE OF ELEMENTARY SUBSTANCES COMPILED FROM THE LIST OF "PRODUCTS OBTAINED FROM COAL," TOGETHER WITH THE SYMBOL. SPECIFIC GRAVITY, ATOMIC WEIGHT AND EQUIVALENT NUMBER OF EACH.

ELEMENT.	SYMBOL.	SPECIFIC GRAVITY.	ATOMIC WEIGHT.	EQUIVALENT NUMBER.	
				H=1	O=100.
Bromine.....	Br.	2.966	80	80.	1000.
Carbon.....	C	3.52*	12	6.	75.
Chromium.....	Cr.	6.000	52	26.27	328.38
Hydrogen.....	H	.069	1	1.	12.5
Nitrogen.....	N	.974	14	14.	175.
Oxygen.....	O	1.106	16	8.	100.
Potassium.....	K	.860	39	39.	487.5
Sulphur.....	S	2.000	32	16.	200.

The equivalent number of hydrogen in this table is 1, and as one part of hydrogen is united in water with exactly eight parts of oxygen, the equivalent number of oxygen is 8. The supposed value of a table like this is, that it serves to show the quantities of other elements which unite with eight parts of oxygen, and it also indicates the simplest proportions in which they can unite with each other.

The equivalent numbers, as given in this table, are seldom used, and the reason why their discontinuance

*Specific gravity of a pure diamond.

was brought about was explained in the section on atomic and molecular weights, page 8.

Energy of Chemical Separation—A combustible body like coal may be taken as a fair representative of potential energy, because it occupies a position of advantage over a non-combustible body in this, that it will unite with another body for which it has chemical affinity like oxygen, and this energy of position leading as it can in this case, to a process of chemical separation during the act of burning, in which we have potential energy or the energy possessed by the coal before ignition, and, the energy due to molecular activity by reason of the act of combustion, or the energy of motion changed or transmuted into another form of energy represented by heat; which, if we choose, may then be again transformed into almost every other form of energy, by suitable trains of mechanism, or other methods; remembering, however, that every time a transformation takes place there is always a tendency to pass, at least in part, from a higher or more easily transformable to a lower form.

The energy of chemical separation, when produced by the combustion of coal, is always intense, and as the observed effects are so much below the theoretical value ascribed to the fuel, it would seem as if for once the law—if there is one—of conservation of energy was at fault. But this is not the case. Our methods of manipulation are so wasteful, and the ordinary construction of furnaces so much at variance with the ideal furnace

—whatever that may be—that a large percentage of waste can be directly accounted for.

One thing with reference to the energy of chemical separation is certain, and that is, that any given quantity of carbon or other combustible, under given conditions, will always produce the same quantity of heat.

THE NATURE OF COMBUSTION—When a piece of rich bituminous coal is thrown upon a brisk open fire, a parlor grate for example, it will be observed that physical changes in this piece of coal rapidly occur. First, a disengaging of small particles of coal, which are often projected from the larger piece with some violence; then a swelling or puffing out of the exterior surfaces of the coal; jets of smoke issuing here and there, proving themselves to be rich in inflammable gases, for soon they burst into a flame, often white and intensely brilliant near the coal, fading into a brownish yellow flame, terminating in smoke. Presently the piece of coal will show indications of cleavage and may split itself into two or more parts. Sometimes this will go on until the whole lump disintegrates, or goes to pieces; at other times, it will continue to swell, expanding to much more than its original volume, giving off its gases, and a caking process is undergone until the whole mass is apparently fused together, after which, the volatile portions of the coal having been expelled and burned, the remaining portion assumes the general incandescent state of the body of the fuel in the grate, disappearing little by little through the action of some unseen

agency, until it yields up all its combustible substance, and ashes alone remain, to mark the completeness of the change.

It would be interesting to know what became of this piece of coal. If, instead of throwing the whole piece in the fire a portion had been retained, it would probably have yielded by proximate analysis,

	PER CENT.
Fixed carbon.....	60
Volatile combustible matter.....	32
Water.....	3
Ash.....	5
	<hr/> 100

The thirty-two per cent. of volatile matter would, upon farther analysis, be found to consist of

Carbon;	Nitrogen;
Hydrogen;	Sulphur.
Oxygen;	

The particular forms in which these elements are usually found to be grouped, are,

Marsh gas.....	CH ₄
Olefiant gas.....	C ₂ H ₄
Hydrogen.....	H
Carbonic oxide.....	CO
Carbonic acid.....	CO ₂
Nitrogen.....	N
Ammonia.....	NH ₃
Sulphurous oxide.....	SO ₂
Bisulphide of carbon.....	CS ₂
Water.....	H ₂ O

and many hydrocarbons not given, the combinations of these two elements being exceedingly numerous; of the above, nitrogen, carbonic acid, ammonia and water, are not supporters of combustion.

In general, carbon and hydrogen are the elements meant when the ordinary term fuel is used, and oxygen is the agent by which they are made to yield up their heat. It is the chemical union of these elementary substances which we shall designate as the particular form of combustion meant wherever the word occurs in this work.

The *exact* nature of combustion is not easily stated. It has been shown elsewhere that coal is composed of ultimate particles called atoms, also that atoms of different substances are attracted toward each other. Both the carbon and hydrogen in coal have an affinity for oxygen; before they unite it is necessary that certain conditions be fulfilled. In the case of coal the oxygen has no apparent effect on it at ordinary temperatures, but once the coal is heated to the point of ignition the oxygen will unite with it, and Prof. Tyndall's theory is: "Oxygen having a choice of two partners, closes with that for which it has the strongest attraction. It first unites with the hydrogen and sets the carbon free. Innumerable solid particles of carbon thus scattered in the midst of burning hydrogen are raised to a state of incandescence. The carbon, however, in due time, closes with the oxygen, and becomes, or ought to become, carbonic acid." The heat and light produced by the burning of coal are due, according to his theory, to the

collision of atoms which have been urged together by their mutual attractions.

A necessary condition to the burning of coal is, that there be a considerable mass of it ignited or burning in order to prevent too rapid cooling; an isolated piece of coal will not burn in the open air, because the temperature will soon fall below the point of ignition, and, as a consequence, chemical action will cease; but an ignited mass of coal under certain conditions—the combustion chamber of a stove, or the grate surface of a furnace, for example—will give off great heat, the intensity of which will depend upon the quality and amount of coal burned, but once the hydrogen and carbon having united with oxygen, and formed by their union, water and carbonic acid, respectively, their mutual attractions are satisfied, and all the heat has been given off that is possible under any conditions.

Whatever may be the real nature of that property of matter called chemical affinity (34), it seems to be a general law that bodies most opposed to each other in chemical properties evince the greatest tendency to enter into combination, and when these chemically dissimilar bodies are brought together under favorable conditions, one very important fact is clearly established with regard to it, and that is, that this chemical union is always accompanied by the production or the annihilation of heat. The measurement of the quantity of heat produced by a given amount of chemical action is a problem not easily solved, but it may be expected that, if a definite quantity of carbon be burned under given

circumstances, there will be a definite production of heat (26), that is to say, a ton of coals or of coke, when burned, will give us a certain number of heat units, and neither more or less.

CONDITIONS NECESSARY TO COMBUSTION.

Carbon, hydrogen, etc., will combine with oxygen in certain definite proportions only. The combining elements must be in immediate contact, not the contact which we usually mean when powdered or liquid substances are mixed together, but the contact which chemical affinity denotes, and this contact must be at a certain temperature in order to produce combustion. Carbon and oxygen will remain in mere physical contact any length of time, but suppose a single atom of carbon be heated red-hot, combustion will begin at once and continue until the supply of either one of the elements is consumed by the other. There is no element in nature which has not an affinity for some other element, but it does not follow that the affinity existing between such bodies shall be accompanied by the evolution of light and heat which are so prominent in the combustion of coal. The oxidation or corrosion of iron, for example, in which a body of iron in a moist atmosphere combines with oxygen and hydrogen, resulting in the formation of a new compound, does so with a slight evolution of heat, but none at all of light.

All solid substances, when heated sufficiently high, emit light. This light may be more or less intense,

according to the temperature of the heated solid. The temperature at which bodies begin to emit red, or the feeblest light in the dark, is about 700° Fahr., and increases in intensity and brilliancy with the higher degree of heat, until it passes successively through the gradations, red, orange, yellow and white heat, which is the highest that can be attained in the furnace; bodies in these states are said to be incandescent or ignited.

Combustion and ignition are not the same thing. The ignition of solids is a source of light: the combustion of solids is a source of heat. Light and heat, though apparently governed by the same laws, are not identical. The combustion of hydrogen with oxygen produces a most intense heat, yet the light emitted is so feeble as to be scarcely visible in daylight; if, however, a piece of lime be introduced into the flame it becomes so intensely brilliant that the eye can not bear it. This piece of lime can not have a higher, nor indeed so high a temperature as the flame itself. The particles of lime in this high temperature become incandescent or ignited, and are the source of the light—if the lime be removed, the intensity of the light is gone, but the heat remains the same; so it would appear that ignition is the glowing whiteness of a body caused by intense heat, or, it is a consequence of combustion instead of a factor in it, the particles which give off the light passing away mechanically, without change of chemical constitution; on the other hand, it is the chemical change in the bodies themselves, and the formation of new com-

pounds, which characterizes combustion, in whatever form it may appear.

That the presence of two bodies is necessary to combustion, is very neatly illustrated in the case of a glass tube containing a gas, through which an electric spark is to pass in order to determine its spectrum. If a single gas would burn in a hermetically-sealed tube upon the application of a spark, these tubes would, after the first experiment, be unfit for the purpose designed; yet the spark may be passed through, the spectrum determined, but the gas remains unchanged.

We have already seen, in the first part of this chapter, that if combustible substances, such as charcoal, sulphur and saltpetre, be intimately mixed together, and the temperature of a portion of the mass be raised to the point of ignition, the combustion is so rapid and violent that it is called an explosion. The combustion in this case is carried on independently of the oxygen of the atmosphere.

FLAME—In the burning of wood and bituminous coal, flame is a marked characteristic, less so in semi-bituminous, and almost entirely wanting in the burning of anthracite and charcoal. Ordinary flame is gas or vapor, of which the *surface*, in contact with the atmospheric air, is burning with the emission of light. The structure of flame, in general, may be understood by a careful study of that produced by an ordinary lighted candle, an illustration of which is given in figure 1. It

consists of three separate portions: the inner portion, A, nearest to and surrounding the wick, is a vapor of the material of which the candle is composed; the second portion, B, is a luminous cone which envelops A, and is that portion of the flame in which chemical action is begun, but which does not seem to be completed until the third portion of the flame, marked C, is reached. It will be understood, of course, that flame does not consist of cones, or envelopes in such contrast as the engraving would seem to indicate; this is for the

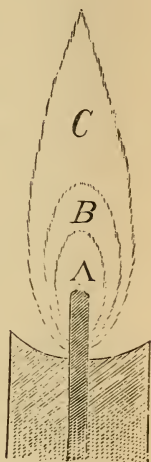


FIGURE 1.

purpose of illustration only. The explanation of the structure of this flame carries us back, to first of all, the application of heat to melt and vaporize the combustible material in the wick, and then ignite it. The constituents of the candle being carbon and hydrogen, the latter being more easily disengaged and set free than the former, and having a greater attraction for oxygen than carbon, unites with it first, and forms a hydrocarbon flame in which the hydrogen is burning, whilst the particles of solid carbon in the flame are heated to a point of incandescence, and produce the light-giving quality of the flame. It is quite probable that the combustion of the carbon is completed, if at all, in the outer envelope C, in contact with the atmospheric air from whence the supply of oxygen is had. It is not known how far the oxygen penetrates the flame, but judging from its great height, as compared with its

diameter, it is quite probable that it is largely, if not entirely, confined to the surface of the cone B; this is inferred from the soot deposited, and lower heat observed, when a piece of card-board is passed through the flame just above the wick, indicating an incomplete combustion, which is not observed when the card-board is held in the apex of the outer cone.

The structure and appearance of flame are modified somewhat by the density of the gaseous matter burning, and by the pressure of the air in contact furnishing the oxygen. This is quite noticeable in the case of steam boiler furnaces operated with, and then without, a forced draft. Firemen, as a rule, judge of the completeness of combustion by the appearance of the surface or flaming portion of the fire. This is a guide which often serves a good purpose, yet it does not reveal the whole secret. It is possible to tell how nearly the prevention of smoke is accomplished, but carbonic oxide, that arch-enemy of economy in furnace combustion, may still be there. The admission of air in the furnace above the grates and near the fuel, serves a useful purpose in igniting the carbonic oxide as it rises from the mass of burning coal; this flame, as exhibited in the burning of anthracite coal or coke, has a bluish tinge, which may easily be distinguished from the brownish-yellow flame produced by the burning of coal rich in hydro-carbons. However, too much dependence must not be placed on the mere appearance of flame, either in its length or color.

Pure hydrogen gas, which yields a most intense heat, burns almost without visible flame; it is so faintly blue as to be scarcely luminous in full daylight. Perhaps the best illustration of colorless flame is shown in the operation of the well known Bunsen gas-burner as fitted for laboratory uses; here, the glowing solid particles of carbon, which give character to hydrocarbon flames, are almost entirely wanting, having been destroyed by intense heat and quick combustion.

It would be impossible to give a description of flame which would be of the slightest service in determining what is going on in the furnace. There are few other than experienced persons who can tell the color of flame in a mass of incandescent fuel; but, allowing this much, to it must be added a knowledge of color and form of flame characteristic of known combustibles when perfectly or imperfectly burned; this only leads into a labyrinth of difficulty and uncertainty which we may well keep out of, and endeavor by other means, much more certain and reliable, to arrive at the facts sought after. This, of course, does not apply to the observation of the oxidizing of foreign substances, so beautifully illustrated in the Bessemer process, where the flame emitted is constantly changing until the impurities are gone, and the brilliant and characteristic light of iron alone remains.

RECENT STUDIES OF LUMINOUS FLAMES (24).

“For a long time Sir Humphrey Davy’s explanation of the luminosity of flames—that it was due to the

presence of highly-heated solid particles—sufficed for all observed phenomena. A serious blow to its sufficiency was given, however, when Frankland discovered that certain flames were luminous under conditions which left no reason for supposing that solid matter could be present. For instance, hydrogen and carbon monoxide, burned in oxygen under a pressure of ten to twenty atmospheres, yield a luminous flame giving a continuous spectrum. So likewise the non-luminous flame of alcohol becomes bright when the pressure is increased to eighteen or twenty atmospheres. Frankland inferred from experiments like these that the luminosity of flames was due rather to the presence of the vapors of heavy hydrocarbons, which radiate white light, than to incandescent solid matter.

“Still further doubt of the prevalent theory was raised by the experiments of Knapp, which proved that the diminished luminosity of a flame on the admission of air could not be due, as had been supposed, to an oxidation of the carbon suspended in the luminous gas, since the same effect was produced when nitrogen or carbon-dioxide, or other indifferent gas, was used as a diluent.

“Stein and Blochmann attributed this effect to the direct influence of the diluting gases in separating the particles of carbon, so that the oxygen of the air might unite with them more quickly than under the ordinary circumstances of combustion. Wibel held, on the contrary, that the diminished luminosity was due entirely to the absorption of heat by the diluting gas, and sup-

ported his view by some very ingenious experiments. The correctness of this conclusion has been, in turn, controverted by the later experiments of Stein and Heumann, particularly the latter, which seem to show that the diminished luminosity consequent upon dilution is due not solely to dilution nor wholly to the cooling action of the added gases, but to both these causes acting together and frequently supplemented by a third cause—namely, the energetic destruction of the luminous material by oxidation. Heumann's experiments, which have been particularly ingenious and careful, lead to the following results: That hydrocarbon flames, which have lost their luminosity by the withdrawal of heat, become luminous again by the addition of heat; that flames rendered non-luminous, by dilution with air or indifferent gases, become luminous again on raising their temperature; that flames rendered non-luminous by excess of oxygen, which brings about energetic oxidation of the carbon, are rendered luminous again by diluting the oxygen in different cases. In most cases of diminished luminosity two or all of these causes are at work.

“Another unsettled question with regard to flames has been the cause of the non-luminous space between the opening of a gas burner and the flame, or between the wick of a candle and the luminous envelope. Blochmann attributed it to the inability of the surrounding air to mix at once with the stream of gas so as to make it combustible. Benevise, on the other hand, thought the dark space due to the mechanical action of the

issuing gas, whereby the air is driven to a distance from the orifice of the burner—greater or less, according to the pressure on the gas, leaving a space wherein the gas is deprived of the requisite amount of oxygen, and consequently remains unburned. Both these explanations are shown to be insufficient by the single circumstance that a flame never directly touches any cold body held within it. In all such cases Heumann finds an explanation of observed conditions in the cooling effect of its surroundings—burner, wick, cold iron, or what not—upon the gas. For a certain space around the cooling body the gas remains at a temperature too low for ignition.

“Where the gas issues under high pressure, or is greatly diluted, the distance of the flame is attributed partly to this same cooling action of its surroundings, but more especially to the fact that the velocity of the stream of gas in the neighborhood of the burner is greater than the velocity of the propagation of ignition within the gas.”

RATE OF COMBUSTION—By this is understood the weight of fuel that can be burned in a given furnace in a given time, but, as applied to steam boilers, it means the number of pounds of coal or coke which can be burned per square foot of grate surface per hour. Sometimes the rate of combustion is expressed as pounds of *net combustible*; by this is meant the pounds of fuel burned, deducting the ashes and other incombustible matter.

The following table is from Professor Rankine's "Steam Engine," showing the rate of combustion of English coals, with a chimney draft; expressed in pounds burned per hour, per square foot of grate surface:

	POUNDS.
1. Slowest rate of combustion in Cornish boilers.....	4
2. Ordinary rate.....	10
3. Ordinary rates in factory boilers.....	12 to 16
4. Ordinary rates in marine boilers.....	16 to 24
5. Quickest rates of complete combustion of dry coal, the supply of air coming through the grate only..	20 to 23
6. Quickest rates of complete combustion of caking coal, with air-holes above the fuel to the extent of 1-36 of the area of the grate.....	24 to 27
7. Locomotives.....	40 to 120

In the experiments carried out by *The Societe Alsaciennes de Constructions Mecaniques, Mulhouse*, the quantity of Ronchamp coal burned per square foot of grate surface in a Lancashire boiler was,

For ordinary firing.....	18.5 pounds.
For slow firing.....	10.15 pounds.
For heavy firing.....	19.01 pounds.

the rate of combustion between slow and heavy firing being almost 2 to 1; in regard to results: the quantity of water evaporated being expressed in equivalent evaporation at atmospheric pressure, and from a temperature of 212° Fahr., was,

For ordinary firing.....	8.94 pounds of water.
For slow firing.....	9.29 pounds of water.
For heavy firing.....	9.06 pounds of water.

During the Centennial Exhibition at Philadelphia, 1876, eight sectional boilers were tested :

1. To ascertain the capacity ;
2. To ascertain the economy, of each.

The following table is collated from the published reports of the trials :

TABLE XIV.

SHOWING THE NUMBER OF POUNDS OF NET COMBUSTIBLE (LEHIGH COAL)
BURNED PER SQUARE FOOT OF GRATE SURFACE PER HOUR, WITH
NATURAL DRAUGHT.

REFERENCE LETTER DESIGNATING BOILER.	GRATE AREA IN SQUARE FEET.	FOR CAPACITY.			FOR ECONOMY.		
		POUNDS OF COMBUS- TIBLE PER HOUR.	RATE OF COMBUS- TION IN POUNDS PER HOUR.	POUNDS OF WATER EVAPOR- ATED PER HOUR, FROM AND AT 212°.	POUNDS OF COMBUS- TIBLE PER HOUR.	RATE OF COMBUS- TION IN POUNDS PER HOUR.	POUNDS OF WATER EVAPOR- ATED PER HOUR, FROM AND AT 212°.
A	42.	613.91	14.62	9.15	469.57	11.18	10.83
B	23.	378.07	16.44	9.89	260.16	11.31	10.93
C	15.41	213.08	13.83	11.06	166.13	10.78	11.99
D	42.	490.77	11.69	10.44	341.71	8.14	12.09
E	27.5	410.52	14.93	8.40	270.81	9.85	10.31
F	30.	373.25	12.44	9.97	248.59	8.29	10.04
G	44.5	622.87	14.00	10.33	3 5.57	8.89	11.82
H	36.	478.46	13.29	9.57	318.41	8.84	10.62

For anthracite coal, the ordinary rate of combustion under stationary boilers may be taken at from eight to sixteen pounds per square foot of grate per hour.

For bituminous coal, from ten to twenty pounds.

In locomotives, Mr. Forney (11) gives the maximum rate of combustion at about one hundred and twenty-five pounds of coal on each square foot of grate surface per hour.

TEMPERATURE OF FIRE—The temperature of combustion is conditioned upon

The nature of fuel burned.

The nature of the products of combustion.

The quantity of the products of combustion.

The specific heat of the gases present in the furnace resulting from combustion; this includes the quantity of air present at the moment of combustion in order to render it complete.

The principal products in the furnace after the combustion of coal are,

Carbonic acid. }

Carbonic oxide.

Nitrogen.

Air furnished in excess, and unconsumed.

Gaseous steam.

In the complete combustion of one pound of carbon we have

Carbon.....	1
Oxygen.....	2.67
Total.....	<u>3.67</u> pounds of carbonic acid.

And in addition to this there would be present in the furnace 8.94 pounds of nitrogen left after the separation of the oxygen from the atmospheric air. We have then,

PRODUCTS.	POUNDS.		SPECIFIC HEAT.	HEAT UNITS.
Carbonic acid.. .. .	3.67	×	.2164 =	.794
Nitrogen	8.94	×	.244 =	2.181
	<u>12.61</u>		Total,	<u>2.975</u>

heat units absorbed in raising the temperature of the products of combustion one pound of carbon 1° Fahr.

The combined weight of the two products are 12.61 pounds.

Then,

$$\frac{\text{Heat units..... } 2.975}{\text{Pounds } 12.61} = .236$$

their mean specific heat.

The total heat of the combustion of carbon is 14,544 heat units; divide this by the 2.975 heat units absorbed, we have,

$$\frac{14,544}{2.975} = 4889^{\circ} \text{ Fahr.}$$

as the highest theoretical temperature attainable by the complete combustion of one pound of carbon.

This is allowing 11.61 pounds of air per pound of carbon, the minimum theoretical limit.

Suppose that eighteen pounds of air are admitted to the furnace, instead of twelve pounds (11.61), and that the combustion is complete, the temperature and products will then be,

Carbon.....	1
Oxygen.....	2.67

Nitrogen	8.94
Air.....	6.39
	<hr/>
	19.00

We then have,

PRODUCTS.	POUNDS.		SPECIFIC HEAT.	HEAT UNITS.
Carbonic Acid.....	3.67	×	.2164 =	.794
Nitrogen.....	8.94	×	.244 =	2.181
Air, uncombined.....	6.39	×	.2377 =	1.519
	<hr/>			<hr/>
Totals.....	19.00			4.494

Then,

$$\frac{4.494}{19.} = .237 \text{ mean specific heat.}$$

$$\frac{14.544}{4.494} = 3236^{\circ} \text{ Fahr.}$$

the temperature of the fire being 1653° less than the first example, showing a loss of 33.81 per cent.

If double the qauntity of air (twenty-four pounds) had been present in the furnace over that needed for combustion the temperature would have been about 2450° Fahr. These examples suffice to show the loss sustained by the admission of too much air in the furnace.

It is scarcely necessary to remind the reader that the combustion of *carbon* is here intended, and not that of coal; this is mentioned, merely, to explain an apparent discrepancy in the next table.

TABLE XV.

SHOWING THE WEIGHT AND SPECIFIC HEAT OF THE PRODUCTS OF COMBUSTION, AND THE TEMPERATURE OF COMBUSTION (2).

ONE POUND OF COMBUSTIBLE.	GASEOUS PRODUCTS FOR 1 LB. OF COMBUSTIBLE.				
	WEIGHT.	MEAN SPECIFIC HEAT.	HEAT TO RAISE TEMPER- ATURE ONE DEGREE FAHR.	TEMPERATURE OF COMBUSTION.	
	POUNDS.	WATER=1.	UNITS.	FAHR.	RATIO.
Hydrogen.....	35.8	.302	10.814	5744°	100
Olefiant Gas.....	15.9	.257	4.089	5219	91
Coal (average).....	11.94	.246	2.935	4879	85
Carbon, or Pure Coke.....	12.6	.236	2.973	4877	85
Alcohol.....	10.09	.270	2.680	4825	84
Light Carbureted Hydrogen.....	18.4	.268	4.933	4766	83
Sulphur	5.35	.211	1.128	3575	62
Coal, with Double Supply of Air..	22.64	.242	5.478	2614	45

AVAILABLE HEAT OF COMBUSTION—The *available* heat of combustion of one pound of a given sort of fuel, is that part of the total heat of combustion which is communicated to the body to heat which the fuel is burned; for example, to the water in a steam boiler.

The *efficiency of a furnace*, for a given sort of fuel, is the proportion which the available heat bears to the total heat, when the given sort of fuel is burned in the given furnace.

The word “furnace” is here to be understood to comprehend, not merely the chamber in which the combustion takes place, but the whole apparatus for burning the fuel and transferring heat to the body to be

heated, including ash-pit, air-holes, flame-chamber, flues, tubes, and heating surface of any kind, and chimney.

The theoretical heat of any given fuel is easily determined, its proximate or elementary analysis being known; but the actual available heat is not so easily arrived at, and can only be determined by a series of more or less elaborate experiments or trials in actual use. In steam boilers the efficiency of the furnace is measured by the pounds of water evaporated per pound of coal burned on the grate, under known conditions. This will always be found to be below the theoretical quantity, and may be accounted for in many ways.

Heat, like water, or steam, must flow from a higher to a lower level in order to become available, and in this flow or transfer there is a loss, which is explained in the article on the dissipation of energy.

There is a loss due to the radiation of heat from the sides of the furnace; this may be prevented in part by building hollow walls around the furnace.

There is a loss in the use of cold instead of heated air for supplying the oxygen to the burning fuel. This may be remedied in part by forcing the air through the hollow space left between the two walls, as suggested in the preceding paragraph.

There is a loss occasioned by the difference of temperature between the escaping gases and that of the atmosphere necessary to produce natural draft. This may be largely overcome by using a forced draft, and dispensing with a chimney altogether, except one sufficient to get rid of the noxious gases; in which case it

will act as an outlet only, the gases being forced into the open air by a pressure behind them, and thus more heat may be abstracted from them than if the temperature were used for assisting the draft.

There is a loss by the waste of unburned fuel passing off as smoke, and that falling through the grates into the ash-pit unconsumed.

There is loss by imperfect combustion, that is, loss by the formation of carbonic oxide instead of carbonic acid.

The consideration of each of these forms of loss has been undertaken elsewhere in this volume, and need not be repeated here. There is no method by which the efficiency of a furnace can be exactly determined, except by an experimental test in actual service.

The quantity of water evaporated from and at 212° per pound of coal, varies in ordinary practice from six to ten pounds; ten pounds is considered a very fair evaporation, and is probably much above the average; this is about seventy-one per cent. of the theoretical, if we assume fourteen pounds, as the average theoretical evaporation power of good coal and coke.

With inferior coal the results would be far below this; the quality of the coal or coke used must be taken into account, as well as the construction of the furnace, and to obtain the highest results, the furnace should have its details arranged with special reference to the burning of a particular fuel, as may be found after a trial, the best and most economical arrangement for that fuel.

CHAPTER VI.

AIR REQUIRED FOR FURNACE COMBUSTION.

Proportions in which Oxygen unites with Carbon and Hydrogen—
Air required for different Fuels—Heated Air for Combustion—
Temperature of Air supplied to Blast Furnaces—The Hoffman
Kiln—Berthier's Theory in regard to Heated Air—Peclet's
Observations—Prideaux' Estimation of the Value of Heated
Air—Difficulties in Heating or Cooling Air—Proportions of Fire-
Brick to Fuel burned in the Siemens Regenerative Furnace—
Ponsard Furnace.

The conditions under which coals are burned are so various that no exact quantity of air can be specified which will supply oxygen enough for complete combustion, and still preserve the minimum dilution of gases passing from the furnace into the chimney. The quantity of oxygen required for the complete combustion of any given quantity of carbon or hydrogen has been experimentally determined, and is well known; the quantity of oxygen present in atmospheric air being constant, the process of determining the amount of air required for the complete combustion of either of these two substances is quite simple.

One pound of hydrogen gas requires eight pounds of oxygen for its complete combustion; this requires about thirty-six pounds of air to furnish it; the product of this combustion being water H_2O .

One pound of pure carbon (not coal) requires two and two-thirds pounds of oxygen for its complete com-

bustion, requiring about twelve pounds of air, the product of combustion being carbonic acid, CO_2 .

One pound of pure carbon (not coal) when only partially or rather imperfectly burned, so as to yield as a product carbonic oxide, CO , instead of carbonic acid, CO_2 , requires one and one-third pound of oxygen, furnished by about six pounds of air.

The following table, by Prof. Rankine (22), shows the theoretical quantity of air required for the different fuels of which the analyses are furnished :

TABLE XVI.

FUEL.	CARBON.	HYDROGEN	OXYGEN.	AIR REQUIRED.
I. CHARCOAL—from wood...	0.93	.....	.....	11.16
CHARCOAL—from peat....	0.80	.....	.....	9.6
II. COKE—good.....	0.94	.....	.....	11.28
III. COAL—anthracite.....	0.915	0.035	0.026	12.13
COAL—dry bituminous...	0.87	0.05	0.04	12.06
COAL—caking.....	0.85	0.05	0.06	11.73
COAL—caking.....	0.75	0.05	0.05	10.58
COAL—cannel.....	0.84	0.06	0.08	11.88
COAL—dry, long flaming	0.77	0.05	0.15	10.32
COAL—lignite.....	0.70	0.05	0.20	9.30
IV. PEAT—dry.....	0.58	0.06	0.31	7.68
V. WOOD—dry.....	0.50	.....	.....	6.00
VI. MINERAL OIL.....	0.85	.....	.....	15.65

The quantity of air, as shown in the above table, represents the number of pounds required for the com-

plete combustion of one pound of the fuel named. The intermediate columns show the proximate constituents of the fuel.

The average number of pounds of air required per pound of coke and coal, appears, from the above table, to be a little less than 11.5 lbs. It is unnecessary for practical purposes to compute the air required for the combustion of fuel to a great degree of exactness; and no material error is produced if the air required for the combustion of any kind of *coal* and *coke* used for furnaces is estimated at *twelve pounds per pound of fuel*. This is to be understood as the theoretical quantity; practically, about twice this amount is supplied; it may be approximately stated that, three hundred cubic feet, or twenty-four pounds of air, are supplied to burn one pound of coal, in boiler and heating furnaces as ordinarily constructed.

HEATED AIR FOR COMBUSTION (8).

“Nearly all the processes in actual use for economizing fuel have for their leading principle that of preheating the air for combustion. This is a pregnant fact, of which many instances can be found. When Neilson made his invention, or rather discovery, in 1829, he began with a temperature in the blast furnace of 50° Fahr., and gradually, in succeeding years, raised it to 600° Fahr. By 1860 this was further increased to 750° and 800°, and from 1854 to the present time it has progressed up to 1,100°, 1,400°, and more. To heat the great volume of air for a large blast furnace some twenty thousand square

feet of fire-brick have to be actively employed. A gas furnace is simply a physical impossibility without using air raised very considerably in temperature above that of the atmosphere; and this was very soon found out by the first experimenters. The Hoffman kiln, which has revolutionized the brick trade, is highly economical in fuel, mainly because the air for combustion is intensely heated by first passing through the already burnt, incandescent bricks. In Siemens' regenerative furnaces, and in the furnaces with direct-acting regenerators of the French engineer, Ponsard, the air and gases for combustion are brought to high temperatures by being conveyed past considerable surfaces of brick, heated by the escaping fire-gases. In Boetius' direct-acting gas furnaces the air is heated by being passed through passages in the brick wall of the producer and other portions of the furnace. In Ireland's and in Krigar and Grothe's cupolas the blast is heated before being allowed to mingle with the products of combustion. It is only by the application of Dr. Geisenheimer's plan of using very hot blast that it is possible to burn American anthracite in the blast furnace. The functions of the deflector and the fire-brick arch now used in locomotive engines for burning coal, mainly consist in heating the atmospheric air and gases for combustion. On the London, Brighton and South Coast Railway this action is intensified by working with the ash-pan almost entirely closed up. A leading feature in Mr. T. Symes Prideaux's contrivances for economizing fuel consisted in pre-heating the air. Several contrivances of smaller fame could be cited as

depending for their success on the use of more or less heated air, such as one or two forms of puddling furnaces and furnace doors. The leading feature of Mr. W. Gorman's gas-furnace is that of heating the air for combustion by means of the escaping fire-gases. Howatson's puddling and heating furnaces, of which a great number were said to have been set up a few years ago, is another instance of the application of heated air, as is also in great measure that of Mr. Price. A furnace which has been described as the Newport puddling furnace may be said to be on a partially regenerative system.

“One obvious reason to account for the effect of the heated air in raising the intensity of combustion, is the mere fact of the attendant elevation of temperature. A current of air sufficiently hot can set wood or coal on fire. But there are several more recondite reasons than this. In the first place, a very high temperature of the air for combustion acts as a corrective whenever too little or too much air is introduced. The French savant, Berthier, gave another reason, which would partly account for several points noticable in the practical working of furnaces. It is based on the very probable hypothesis that the chemical affinity of heated air for carbon is much greater than that of cold air. As observed by Peclet, one consequence is, that when heated air is employed, it is deprived of oxygen within a very short travel. The combustion is thereby more concentrated and localized at the focus where the heat has to be applied and to do its work. At the spot required

the heat is higher, and at the same time beyond it lower. These two circumstances are favorable to the economy of fuel, for combustion and high temperature beyond the point where heat has to be applied are useless. It has thus been found in practice that the greater the affinity of any fuel for oxygen, the lower need be the temperature of the air. It is hence used at a lower heat in charcoal furnaces than in coke blast furnaces, and less in the latter than in furnaces fed with anthracite. This explains the fact, which has been found on trial, that a reverberatory furnace, supplied with hot air at the grate only, has actually been found to have its efficiency diminished, and not increased. The gaseous combination or chemical union being thereby accelerated, the combustion takes place more on the grate and less in the body of the furnace, where the actual work has to be done.

HEATED AIR AND CHEMICAL ACTION.

“While heating the air for combustion intensifies the chemical affinities between the air and the fuel, the process offers another most effective means of diminishing the consumption of fuel, and of almost indefinitely increasing the intensity of the fire. By applying the fire-gases—which are useless where they are only *equal* in temperature to the goods to be heated—to pre-heating the air for combustion, an actual recuperation, returning, or carrying back, of the heat is caused. This amount saved can be exactly expressed by the product of the weight of the air thus returned for use in

combustion into the actual temperature given it, and its specific heat.

“The exact mode of estimating this was first indicated by Mr. J. S. Prideaux, and adopted by Rankine. According to results of experiments made with the mercurial calorimeter—of course, under conditions unrealizable in practice—one pound of carbon, combined with its equivalent by weight, or two and two-third pounds of oxygen, will develop fourteen thousand five hundred British units of heat, or will raise fourteen thousand five hundred pounds of water one deg. Fahr. But, to effect the combination in the atmosphere, this amount of oxygen has to be taken in conjunction with the nitrogen of the air, amounting to nine and one-third pounds. In other words, the very least amount of atmospheric air used in combustion is twelve pounds; it is in many furnaces, especially those working with a chimney draught, required to be twice as much, or twenty-four pounds. Assuming the most probable case, that twenty-four pounds of air per one pound of carbon be taken, and that this carbon has been completely burnt, then, as atmospheric air consists of eight parts by weight of oxygen and twenty-eight of nitrogen, the products of combustion resulting from the one pound of carbon and the twenty-four pounds of air, weighing in all twenty-five pounds, will consist of three and two-third pounds of carbonic acid and twenty-one and one-third pounds of inert, uselessly heated nitrogen. It is clear that, for instance, the more nitrogen there happened to be mingled with oxygen, the greater the

weight of matter that would have to be uselessly raised in temperature; and that the greater its capacity for absorbing heat—the greater its specific heat—the greater the amount of heat that would be taken up.

“We need scarcely observe that the so-called specific heat of any body is that amount of heat which it absorbs or gives out whenever its temperature rises or falls respectively; and the unit of measure in the scale of specific heat is that of water. Thus, the specific heat of carbonic acid gas being 0.217 and of nitrogen 0.245, the mean of three and two-third pounds of the first and twenty-one and one-third pounds of the latter is 0.237; this, multiplied by the weight, twenty-five pounds, and divided into the fourteen thousand five hundred units of heat which can be generated from a pound of carbon, gives $2,440^{\circ}$ as the temperature of the products of combustion, in the form of about one thousand eight hundred cubic feet of fire-gases.

“From these figures alone is seen the paramount importance of thoroughly heating the air for combustion, of thoroughly heating its oxygen in order to facilitate combination with the carbon, and of preliminarily heating its nitrogen in order that its fourfold useless volume may not rob the heat required at the very moment and focus of combustion. Now, it is evident that the nearer the temperature of the useless nitrogen is raised to that of the fire, the less is the loss to the fire in unnecessarily heating it while it is parting with the oxygen; and whatever of this can be done by

means of the very escaping gases themselves is pure saving.

“The very great difficulty in either heating or cooling air is its non-conducting capacity, or, more strictly speaking, the difficulty in obtaining a sufficiently rapid convection of heat to and from the mass of air employed. This is too well known to all contrivers of hot-air engines or of air-cooling machines; in cold climates it constitutes the comfortable properties of flannels and furs. To heat or cool air, very extensive surfaces, together with very great differences of temperature, are hence absolutely necessary. We believe that the Siemens regenerators are proportioned in such-wise as to give about seventeen pounds of fire-brick for each increment of gaseous fuels that can be developed from one pound of coal. As, however, only about one-fourth of the total regenerative capacity is being heated to the full temperature of the gases passing down through the ports, this amount has to be increased fourfold; so that nearly seventy pounds of fire-brick are probably used per pound of product of combustion. The surface of a Ponsard recuperator for an ordinary re-heating furnace is stated to average twenty-three square metres, half of which is for cooling the fire-gases, and the other half for heating the air; and therein the air is stated to attain the temperature of $1,500^{\circ}$ Fahr. When, as in the Boetius furnace, the sides or the top or bottom of the furnace are used to heat the air, the air is, firstly, not merely heated, but, secondly, it serves as a cooling

medium—protecting the brickwork by keeping down the temperature. The heat, also, that would otherwise be uselessly radiated is thus picked up by the air during its circulation, actual trials with the pyrometer having shown that the air can be heated in this way up to 600° Fahr.”

CHAPTER VII.

THE FURNACE.

Furnace Draft—Sectional Area of Chimneys—Height of Chimneys—Volume of Escaping Gases—Weight of Escaping Gases—Temperature of Escaping Gases—Distribution of Air in the Furnace—Admission of Air Over the Fire—C. Wye. Williams' Plan—T. S. Prideaux' Plan—W. A. Martin's Plan—Experimental Test of the Martin-Ashcroft Furnace Door at U. S. Navy Yard, Washington—Perforated Pipes—Admission of Air at the Bridge-Wall—R. K. McMurray's Plan for Admitting Heated Air—Admission of Air and Evaporation.

FURNACE DRAFT may be produced by any one of the following methods:

1. A natural chimney draft, or that due to the unbalanced pressure of a column of heated gases. This may be modified;

2. By the use of a jet of steam escaping into the chimney through a contracted orifice, by which an increased draft is obtained over that given above; this may be either "live" steam from the boiler or the exhaust from a non-condensing engine.

3. By a forced draft produced by a fan-blower, or other device.

The first is almost exclusively employed in connection with stationary steam boilers. The object of chimney draft is to supply oxygen to the burning fuel, and then, to get rid of the products of combustion.

The sectional areas of chimneys usually bear some empirical relation to the area of the grate. In practice

this sectional area varies from one-sixth to one-tenth of the grate. After a series of elaborate experiments Mr. Isherwood fixed upon one-eighth of the area of the grate as being the best proportion for draft area, and which will be near enough for the area of chimneys in any ordinary practice.

The height of the chimney is often determined by the character of the surroundings, such as buildings, hills, etc., and in cities, the minimum height is not unfrequently fixed by local legislation; but aside from this, there is a great deal of "rule of thumb" about it. The building of a chimney costing, say from two thousand to five thousand dollars, is designed not only for present, but for prospective future needs, and the desire is, that it shall be amply large for an uncertain future requirement.

Within reasonable limits there is no objection to a large, and especially a high chimney—other things being equal—the higher the chimney the better the draft.

Furnace draft is caused by the difference in weight or pressure of the column of cold air outside of the chimney, and the weight of the column of heated gases within it. Air and gases, when heated, expand in volume, and become less dense than for equal volumes at a lower temperature; this difference in density is the draft-producing quality of heated gases. The increase in volume, for different temperatures, has been calculated by Professor Rankine. The following are some of the results :

TABLE XVII.
SHOWING THE VOLUME OF ESCAPING GASES IN CUBIC FEET PER POUND
OF COAL BURNED.

TEMPERATURE.	POUNDS OF AIR PER POUND OF COAL.		
	12 POUNDS.	18 POUNDS.	24 POUNDS.
FAHR.	CUBIC FEET.	CUBIC FEET.	CUBIC FEET.
32°	150	225	300
68	161	241	322
104	172	258	344
212	205	307	409
392	259	389	519
572	314	471	628
752	369	553	738
1112	479	718	957
1472	588	882	1176
1832	697	1046	1395
2500	906	1359	1812

From the above table it will be seen that if 225 cubic feet of air, at a temperature of 32° are necessary for combustion, it will require 241 cubic feet, if supplied at 68°.*

Supposing 241 cubic feet of air at a temperature of 68° are supplied to the furnace per pound of coal burned per hour, the volume of escaping gases will be increased when discharged into the chimney to 471 cubic feet, if the temperature of the escaping gases is 572°.

*It will be a near enough approximation in this case to assume that the products of combustion and air will, at the same temperature, occupy similar volumes.

The weight of escaping gases will equal the weight of the air and the combustible portion of the fuel. At two hundred and twenty-five cubic feet, as above, there are required eighteen pounds of air to one pound of combustible; the increase in volume from two hundred and twenty-five, to two hundred and forty-one cubic feet does not change the weight of the air, but the four hundred and seventy-one cubic feet of gases, instead of weighing eighteen pounds, will weigh $18 + 1 = 19$ pounds.

We can then suppose two columns, one of air at a temperature of 68° weighing eighteen pounds and occupying two hundred and forty-one cubic feet, and one of gases, at a temperature of 572° , weighing nineteen pounds, and occupying four hundred and seventy-one cubic feet. The lighter gases being confined to the chimney, rise to the top by virtue of their lesser gravity; the higher the chimney, and the higher the temperature of the escaping gases, the stronger or more intense will be the draft.

In height, chimneys usually vary from forty to one hundred and twenty feet; it is seldom that the latter figure is exceeded, and when it is, it is generally for other reasons than for draft simply. A table prepared by Mr. Theron Skeel, gives the relative amount of coal that can be burned in the same time, with chimneys of various heights, as follows:

Height of chimney, in feet.....	120	100	80	60	40	20
Relative amount of coal.....	100	90	80	70	57	40

After a moderate height of chimney is reached, the effect of any increased height is very small. It rarely occurs that a height of more than one hundred feet is needed for draft even when permanent chimneys are to be built. When iron chimneys are employed the heights commonly vary between forty and seventy-five feet.

Knowing the rate of combustion, and the area of the chimney, the following rule of Boulton and Watt for determining the height of the chimney is a good one, taking into account all the uncertainties attending chimney proportions :

RULE—Multiply the number of pounds of coal consumed under the boiler per hour by twelve, and divide the product by the sectional area of the chimney in square inches ; square the quotient thus obtained, which will give the proper height of the chimney in feet.

This very closely approximates Peclet's formula, so elaborately presented by Professor Rankine in his treatise on the steam engine, and to which the reader is referred for the mathematics of chimney proportions ; also, Weisbach's *Mechanics*—DuBois—vol. 2, part 2 ; or Trowbridge's *Heat and Heat Engines*.

The connection between the boiler and chimney should be as short and direct as the circumstances will permit. The area of the chimney should be one-eighth of the grate. The grate should be of such size as to burn all the combustible matter without loss, and without forcing the fire beyond the point of economic combustion.

The best temperature for the escaping gases is held in practice to be nearly, but not quite, that sufficient to melt lead, that is, a temperature a little below 600° Fahr.

It is especially worthy of remark, that a moderate force of draft through the fuel seems to be the condition which is best suited to the fullest economical performance, speed and power both considered, of the semi-bituminous and bituminous coals, while to the anthracites a strong current is best adapted for the same ends.

The maximum heating effect from any coal is procured when the air passes through it fast enough to burn entirely all the combustible matter it can surrender to it by its own heat; but when the current exceeds this rate, its influence is *counteractive*, cooling and quenching a portion of the burning matter, and driving it wastefully forward, with the combustion not completed. The different ignitibility of the various classes of fuel sets, of course, different limits to this point of economical rapidity of blast and of combustion—limits which are sooner passed with the bituminous than with the anthracite coals.

Distribution of Air in the Furnace—Air, when admitted through the ash-pit, and coming in contact with a mass of incandescent coke or anthracite coal on the grate, yields up its oxygen and combines with the carbon of the fuel; first, in the proportion to form carbonic acid (CO_2), then, in passing through this bed of ignited fuel takes up another equivalent of carbon, and converts the carbonic acid (CO_2) into carbonic oxide (CO).

Supposing the heat units of the net combustible, when burned to carbonic acid, to be, say, 14,000; if burned to carbonic oxide, the heat units would amount to, about, 4000, showing a difference of, say, 10,000 heat units per pound of net combustible, or more than seventy per cent. of loss, perhaps *waste* would be a better word, for air costs nothing, and oxygen is all that is needed to effect the saving.

The distribution of air above and below the fire is intended to counteract this loss, by supplying air under the grate to burn the fixed carbon or coke, and above it, to supply the oxygen needed to re-convert this carbonic oxide into carbonic acid.

In the burning of a coal rich in hydrocarbons smoke is produced in large quantities, and if these particles of solid carbon are mixed with carbonic acid gas while still in the furnace and at a high temperature, they disappear as smoke, and convert the carbonic acid already formed in the furnace into carbonic oxide, by yielding up their carbon to the heated gas; most, if not all of which, might have been prevented by slow combustion, and a proper supply of air *above* the fuel.

The quantity of air to be admitted above the fire and the best relative position for its admission, is a matter of furnace detail to be determined and fixed by experiment, rather than one pertaining to the theory of combustion. It is one of great importance, however, and is entitled to more consideration than it generally receives.

C. WYE. WILLIAMS' FURNACE DOOR.

Mr. Williams has given this subject a great deal of attention, and recommends a fire-door consisting of two plates; the door proper, with an opening through it, and another plate as near the size of the fire-door opening as possible and allow the door to be closed; this plate may be from two to three inches back of the fire-door plate, and should contain as many perforations about $\frac{5}{16}$ inch diameter as will make the aggregate area of these perforations $\frac{1}{36}$ of the grate surface.

The air may be admitted through the fire-door into the furnace at a constant rate, or, the flow of air may be checked by the closing of a "butterfly" register on the outside of the door. This fire-door has worked well in practice, especially with anthracite coal.

THE PRIDEAUX FURNACE DOOR.

Invented by Mr. Thomas S. Prideaux, England, is represented in plate I, and is thus described in the specification of his American patent:

"This invention relates to apparatus for regulating the supply of air to furnaces in such a manner as to afford the furnace an additional supply of air after coal-ing, which supply shall gradually diminish and eventually cease after a certain definite period of time by the action of an automatic apparatus, thus securing the cutting off of the additional supply of air, when no longer required, independently of the attention of the fireman.

"The apparatus consists of two parts: First, a case or air-chamber in the exterior of the furnace, furnished

with a flap or cover moving on an axle, so as to admit or exclude the air at pleasure, and communicating with the interior of the furnace through the fire-door and two channels placed laterally, the exit-mouths of these passages being furnished with grating suitable for heating and distributing the air as it passes into the furnace, and at the same time preventing the radiation of heat outward, while the throat of the air-chamber is furnished with a damper moving on an axle, which, according to the angle its surface makes with the axis of the line of draft, interposes a greater or less impediment to the influx of air, thus affording the means of varying the quantity of the supply according to the character of the fuel and the urgency of the firing. Secondly, a motor-regulator, by which the gradual closing of the lid of the air-chamber is automatically effected. This motor-regulator consists of, first, a cylindrical cup or cistern pierced with a small orifice at the bottom and having a rod rising from its center; secondly, a cast-iron cylinder, about one and a half times the depth of the cistern, and sufficiently larger in diameter to admit of the cistern traversing freely within it when the apparatus is charged with mercury, and having a cylindrical block or plunger attached to the under side of the cover, pierced in the center for the passage of the cistern-rod, which plunger is to be of a diameter as much less than the interior of the cistern as will allow of the free passage of the mercury, thus enabling the cistern to be rapidly raised to the top of the cylinder.

“The manner in which my said invention is best carried into practice may be fully understood by the aid of the accompanying drawing, which I will now proceed to describe.

“Figure 1 shows a front elevation of an apparatus to be applied to the mouth of a furnace, and constructed according to my invention. Figure 2 is a cross-section of the same through the line A B. Figure 3 is an end elevation. Figure 4 is a longitudinal section through the line C D. Figure 5 is a horizontal section through the line E F, and Figure 6 is a back elevation of the said apparatus. Figures 7, 8, 9 and 10 are hereinafter described.

“The apparatus works as follows: The charge of mercury is placed in the cistern at the bottom of the cylinder, and the cylinder-cover screwed down. Upon the cistern being raised to the top of the cylinder the plunger enters the cistern, displacing the mercury and causing it to flow over its sides and pass down the circumferential interstice to the bottom of the cylinder. The raising of the cistern is effected by the lifting of the lid of the air-chamber, while the weight of the latter, slightly depressing the cistern, causes the mercury to rise in the circumferential interstice between the cylinder and the cistern to a height considerably above the level of the bottom of the cistern. The mercury, as a consequence, flows into the cistern through the small orifice in a time proportionate to the size of the orifice, the amount of the charge of mercury, and the force of gravity exerted by the suspended weight.

“To prevent the access of dust or steam to the interior of the motor-regulator, I construct a closed channel, *l*, on each side of the exterior of the cylinder, extending throughout its length, for the passage of the side rods *s* from the cross-head *k*, the cross-head itself being covered with a hood or cup, *o*, the lower edge of which is in apposition with the upper faces of the lateral channels, by which the access of dust or steam is effectually prevented.

“An alternative plan for excluding the entrance of dust or steam, compact and elegant in appearance, but entailing slightly more friction and requiring greater delicacy and accuracy in workmanship, is to construct the cistern-rod *f* hollow, so as to enable it to contain within it, and travel freely upon, a small tube, *u*, securely tapped into the bottom of the cylinder.

“This tube must be of such a size as to allow of the traverse within it of a small rod, *r*, which may be termed the connecting-rod, attached at its upper end to the top of the cistern rod (or rather tube) by a pin-joint, *i*, and at its lower to the lid of the air-chamber by a short link.

“To enable the motor-regulator to sustain a heavier weight, thus lessening its liability to derangement by friction, and at the same time affording within certain limits the means of varying the time occupied in its descent, I apportion the depth of the plunger *h*, cistern *d*, and cylinder *g*, so that the edge of the cistern considerably overlaps the bottom of the plunger. As the velocity with which the quicksilver traverses through

the orifice and enters the cistern increases with the pressure, the wider the range of pressure available the greater the power of varying at pleasure, by means of movable weights, the time of the descent and the closure of the air-valve.

"To prevent the interior of the motor-regulator becoming rusty, thus giving rise to a friction which impairs its action, I heat it in detached pieces to a temperature of about 600° or 700° , and then plunge it into warm linseed-oil, after which it is carefully wiped and then thoroughly washed with benzoline.

"*a* shows the exterior air-case divided into three-chambers or passages, *b*, the cover or damper connected by a link to the connecting-rod attached to the cistern-rod, of the motor-regulator or cylinder *g*. The cover or damper *b* of the air-chamber may be opened by the fireman when he closes the door after coaling, but I prefer to make it self-opening by the aid of the segment of a screw, *y*, formed on the hinge of the furnace-door, which raises a lifting-bar, *z*, upon the door being opened. *c* is the grating for heating and finely dividing the air on its passage into the furnace, and at the same time assisting in conjunction with the plates of sheet-iron *t* (having vertical slits or openings so placed that the intervals shall not correspond), to prevent the passage of the radiant heat outward. *p* is the flap, the office of which is to vary the size of the neck of the air-chamber. *w'* is a movable weight suspended from the tip of the link, which attaches the

connecting rod to the cover of the air-chamber, and which is furnished with a small hole for the purpose.

“Figure 7 shows a vertical section of the motor-regulator with a hollow cistern-rod. Figure 8 is a horizontal section of the same. *g* is the cylinder; *d*, the cup or cistern. *h* is the plunger, which displaces the mercury, and causes it to flow over the rim of the cistern into the cylinder when the cover of the air-chamber is raised. *f* is the hollow cistern-rod; *e*, the orifice for the passage of the mercury; *u*, the tube tapped into the bottom of the cylinder; *w*, a weight, advantageously placed to assist by its gravity in overcoming any friction opposing the closing of the apparatus; *o*, the hood or cap for excluding dust and steam. *m* is the connecting-rod, and *i* its pin-joint. Figure 9 shows a vertical section of the motor-regulator, with a cross-head and closed channels for the passage of the side-rods. Figure 10 is a view of the same, seen from above, showing the hood or cap, and the channels for the passage of the side-rods. *g* is the cylinder; *d*, the cup or cistern; *h*, the plunger; *f*, the cistern-rod; *e*, the orifice for the passage of the mercury; *o*, the hood or cap for excluding dust and steam; *k*, the cross-head; *s*, the side-rods, and *l* the channel for the passage of the side-rods.”

THE MARTIN FURNACE DOOR.

The furnace-door, of which Figure 2 is a sectional representation, is the invention of Mr. W. A. Martin, of England, and is now being introduced in this country by the Ashcroft Manufacturing Company, Boston, Mass.

T. S. PRIDEAUX.

APPARATUS FOR REGULATING THE SUPPLY OF AIR
TO FURNACES.

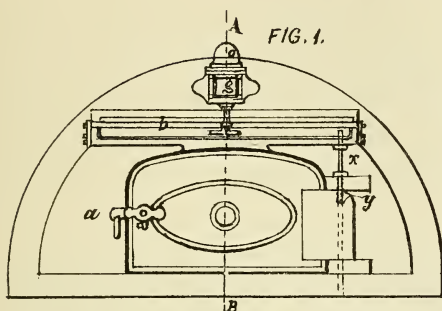


FIG. 1.

FIG. 2.

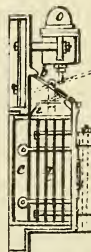


FIG. 3.

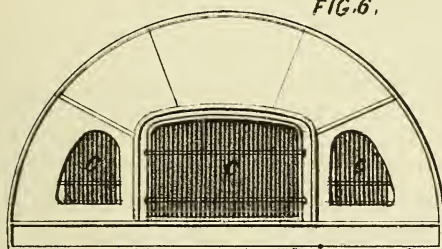
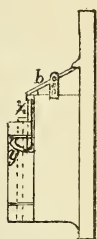


FIG. 6.

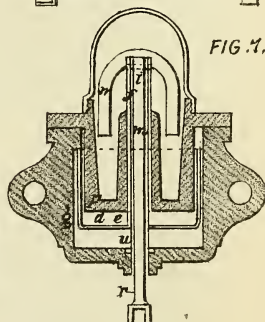


FIG. 7.

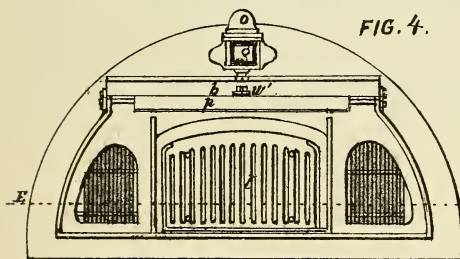


FIG. 4.

FIG. 8.

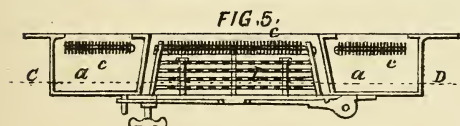
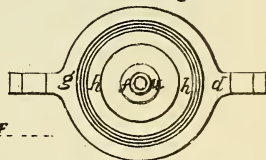


FIG. 5.

FIG. 9.

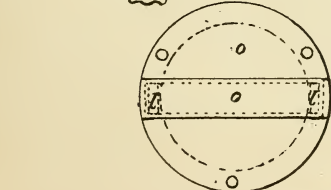
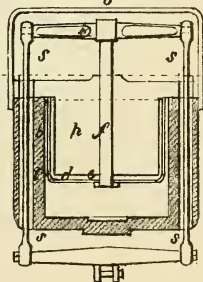


FIG. 10.

This door consists in the combination of a furnace door, pivoted on a horizontal axis, at, or near, its upper edge, and made to open and close by being swung pendulum-like through the lower arc of a circle, and a counterbalancing-weight for retaining the door in the desired position.

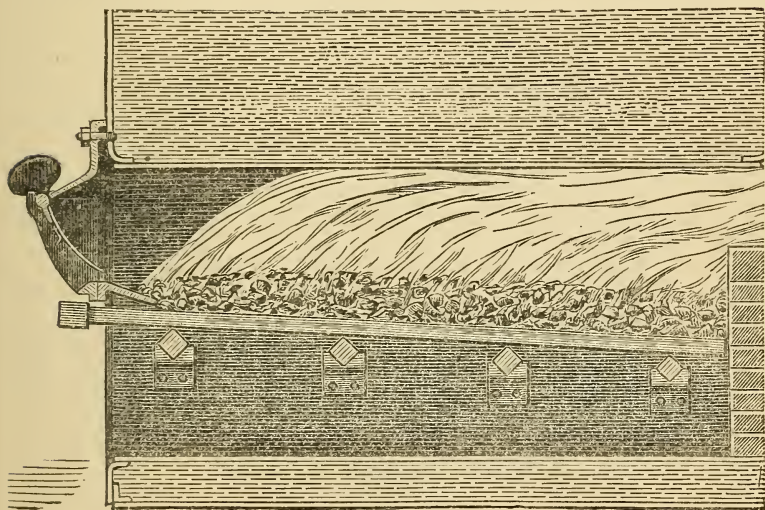


FIGURE 2.

By opening this door a few inches inwardly the air is caused to enter and pass among the fuel, and to mingle with the gases proceeding therefrom in the process of combustion after they rise from the fuel, thus causing them to unite and to be consumed before leaving the furnace, instead of leaving it in the condition of smoke, or unburned gases; and by opening it outwardly to the required extent, ample provision is made for the insertion of the fuel.

Experiments were made at the Washington Navy Yard, in 1874-5, to determine the relative economy of this furnace-door, over the ordinary door, the latter being that recommended by C. Wye. Williams, and described on page 143.

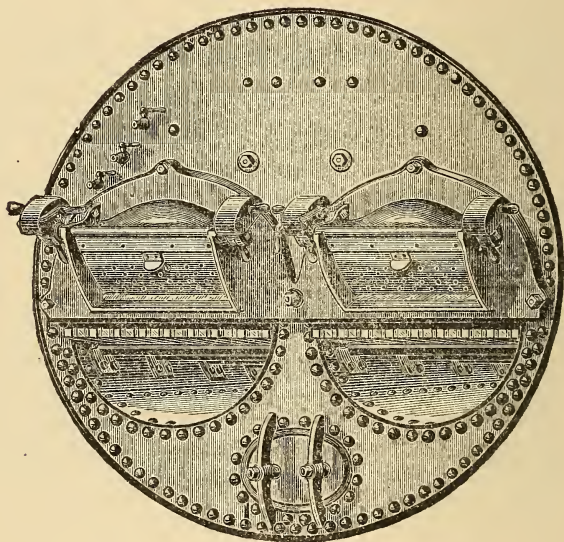


FIGURE 3.

Figure 3 is a representation of a front view of the boiler, as fitted with the experimental door, and the following table gives the comparative results:

TABLE XVIII.—GIVING A TABULAR STATEMENT OF RESULTS OF BOILER EXPERIMENTS WITH THE ORDINARY FURNACE DOOR AND GRATE, AND WITH THE MARTIN-ASHCROFT FURNACE DOOR AND GRATE.

	EXPERIMENT MADE IN 1874.		EXPERIMENT MADE IN 1875.
	ORDINARY DOOR AND GRATE.	ASHCROFT DOOR AND GRATE.	ASHCROFT DOOR AND GRATE.
USING CUMBERLAND COAL.			
Duration of the experiment, in hours.....	72	72	12
Temperature of water in boiler at beginning of experiment.....	92°	59°	
Pounds of water in boiler at beginning of experiment.....	14,786.3	14,852	
Pounds of dry pine wood used in starting fires.....	173¾	191	
Equivalent of wood used in pounds of coal.....	76¾	84½	
Mean pressure of steam, per gauge, in pounds, per square inch, during experiment.....	30.69	30.04	20
Mean temperature of feed-water.....	62°	48.83°	65°
Mean temperature of the air.....	59.5°	64°	
Mean height of barometer.....	30.30	30.26	
Total pounds of coal consumed during the experiments.....	14,181.5	10,961.5	2,187
Percentage of ashes.....	1,564.5	1,180	196.83
Pounds of water evaporated from temperature of feed-water under mean boiler-pressure.....	11	10¾	9
Estimated mean temperature of water in boiler during the experiment.....	122,367.4	115,609.3	
Pounds of water that could have been evaporated from temperature of feed-water under mean pressure by heat required from the fuel to raise water in the boiler, at beginning of experiments, to mean temperature.....	205°	204.5°	
Total pounds of water evaporated from temperature of feed-water under mean boiler-pressure..	1,481.3	1,901.66	
Pounds of water evaporated from temperature of feed-water under mean boiler-pressure per pound of coal.....	123,848.7	117,511	22,785.2
Equivalent evaporation from and at 212° per pound of coal.....	8.73	10.72	11.438
Percentage of evaporation in favor of the Ashcroft Door and Grate.....	10.27	12.64	13.62
		2: +	91
			27 100

* The large percentage of gain as shown in the trial of 1875, over those of 1874, was due to the short time the boiler was in use, not having time to become foul.

The boiler with which these experiments were made is of the cylindrical, horizontal, tubular type, seventeen feet eight inches long, six feet in diameter, containing one hundred and fifty-seven brass tubes, ten feet long, and two and one-fourth inches outside diameter; having two furnaces, with a combined grate-surface of twenty-two square feet; and a heating-surface of nine hundred and twenty-eight square feet.

The doors have an opening of one hundred and eighty-six square inches each, and are constructed in the usual manner, with an outer shell of cast-iron, containing seven one and one-fourth inch holes, and with an inner plate of wrought iron with a space between them of three inches, the inner plate being perforated with small holes through which the air is distributed over the fuel.

Perforated Pipes—Instead of admitting the air through the furnace door, as described in the preceding pages, it is sometimes admitted through the sides of the furnace above the fuel, and sometimes back of the bridge-wall; perhaps the device most frequently used for this purpose is a cast-iron pipe, about six inches in diameter, and perforated with small holes; the determining of the aggregate area of these perforations does not seem to rest upon anything in particular, and is almost entirely a matter of caprice; this pipe extends into, or through, the combustion chamber under the boiler, and is built into the walls, the ends of the pipe being left open to the air. Whenever a device of this kind is employed it should never be far removed from

the bridge-wall, and it is, at best, of doubtful utility if, by this means, an excess of cold air is allowed to pass into the chamber back of the bridge-wall; for it should be remembered that oxygen alone is not what is needed, but a high temperature also, to insure the ignition of the carbonic oxide, which is the only reason for its admission at all.

Admission of Air at the Bridge-wall—The admission of air at this particular point is intended to supply the oxygen needed to complete combustion in case it should be imperfect, while the gases are still at a high temperature. A very successful device for the admission of *heated* air, near the point of the generation of gases in the furnace, was patented by Mr. R. K. McMurray, New York City, and is shown in plate II.

“The improvement consists in combining with the furnace and combustion chamber a hollow cast-iron fire-bridge, formed of a series of plates united together and resting on the top of a bridge-wall of the ordinary construction, without being imbedded therein, into which hollow bridge fresh air for supply to the combustion chamber is introduced, and within which it is heated to a temperature approximating to that of the gases escaping from the furnace, and is thence delivered, in a minutely divided condition, to the gases as they enter the combustion chamber. The improvement further consists in such construction of the fire-bridge as to provide ample resistance against blows or shocks, and the effects of expansion and contraction, as well as to render it capable of being readily and quickly removed

from its position in the setting, renewed or repaired at a comparatively slight expense, and replaced in position for further operation.

“The construction of the fire-bridge and its application in the setting of a return tubular stationary boiler, are clearly shown in the accompanying illustration. It consists of a fire-plate *A*, a back or base-plate *B*, and a dispersing-plate *C*. The plate *A* is corrugated in order to give it increased strength, and allow for expansion and contraction under change of temperature, and is provided with a light-bottom flange, which rests upon the bridge-wall, and thence rises vertically for about two-thirds of its height, at which point it is inclined at an angle of about forty-five degrees. The bottom plate *B* conforms in the relative position of three of its sides to the plate *A*, and terminates below in a horizontal foot. The plates *A* and *B* are connected by bolts passing through thimbles, so as to form a hollow case. The perforated diffusing-plate *C* is inserted in grooves formed in the other plates. A series of air-supply openings *D* are formed in the plate *B*, near the base; above them extends a deflecting flange, *E*. The bridge so set that the lower edge of the fire-plate *A* is slightly below the level of the grate-bars, and its ends are closed by the side walls of the setting, or by metal plates fitted therein; the latter arrangement allowing of the bridge being removed when desired by drawing it out longitudinally through the opening in the side wall.

“The fresh air enters the space between the back plate and the fire plate through the supply openings *D*

and is deflected by the flange against the heated surface of the fire-plate, and thence passes upward, as indicated by the arrows, figure 2, along the space between the two plates. The air is thus introduced in a minutely divided condition into the combustion chamber at a temperature closely approximating that of the gases escaping from the furnace. It mingles with these gases and oxidizes the carbonic oxide, effecting complete combustion with a corresponding economy of fuel and prevention of smoke.

“In applying the bridge in a setting it is placed upon the top of the usual brick bridge, the lower edge of the fire-plate *A* being slightly below the top of the grate-bars. It can be removed whenever necessary by being drawn out longitudinally through an opening in the side wall, without disturbing any of the brick work of the bridge on which it rests, or any other part of the setting, and replaced in a similar manner. This can be done in a very short time, and without the necessity of awaiting the cooling down of the furnace and combustion chamber. The capability of ready removal and replacement for renewal or repair constitutes an important and valuable feature of the improvement as compared with the ordinary brick bridge-walls, or with devices imbedded therein, or in the setting.

“Its advantage, moreover, in durability will be apparent to the practical engineer and steam user, inasmuch as the fire-plate only is exposed to the direct action of the fire; and, from its material and form of construction, is possessed of greater power of resistance to the des-

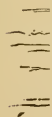
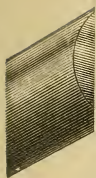
tructive influences exerted upon it. In the event of repair the entire bridge can be removed, a new fire-plate be inserted, and the bridge replaced in position, with much less labor and expense, and with far greater expedition, than is practicable in the case of a brick bridge-wall.

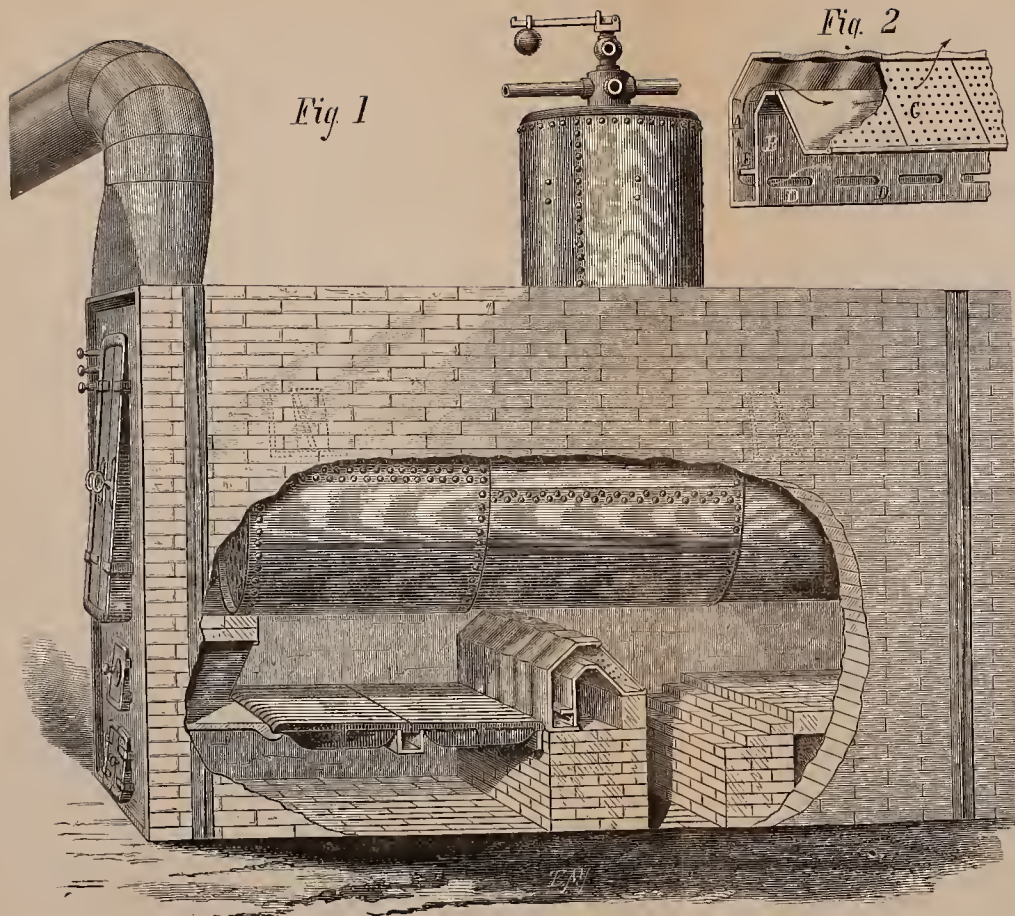
“The bridge is adaptable to any shape or size of furnace used in conjunction with steam boilers, re-heating furnaces, blast furnaces, and tan-bark ovens, without change in the brick work or setting, other than removing the upper portion of the brick bridge-wall, and forming an opening in the side wall for the insertion of the bridge.”

This bridge-wall has been adopted by the Hartford Steam Boiler Inspection and Insurance Company, in their system of boiler settings, and is said by them to give good results in practice.

The admission of air above or beyond the fuel is not always to be regarded as a remedy for the low evaporative efficiency of a boiler or the low heating power of coal under all conditions. Sometimes this admission of air may prove to be of the greatest value; under other conditions, it may not be of the slightest service, and, indeed, it may lower the temperature of the furnace so far below the point of economy as to prove an evil instead of a remedy.

Unfortunately there is no way in which this question can be finally settled, except by direct experiment, and this would apply to one particular furnace only, and perhaps for only one particular kind of coal, *i. e.*, either





McMURRAY'S CORRUGATED IRON AIR BRIDGE WALL.

anthracite or bituminous, but not both. As the subject now stands, it amounts to little less than a mere speculation to predict in advance the performance of any furnace, in so far as perfect combustion is concerned, but in general terms it may be said that, if the performance of any boiler has an equivalent evaporation of less than ten pounds of water, from and at a temperature of 212° Fahr. per pound of net combustible, there must certainly be something wrong in the construction of the boiler, furnace, or setting, which demands immediate attention.

CHAPTER VIII.

PRODUCTS OF COMBUSTION.

Carbonic Acid—Carbonic Oxide—Water—Nitrogen—Sulphurous Oxide—Surplus Air—Smoke—Products of Perfect Combustion Invisible—How Soot is Formed—Smoke-preventives—The Corrosive Action of Sulphur on Boilers—Ashes and Clinker—Analysis of Coal Ashes—Color of Ashes as Indicating the Presence of Iron Pyrites in Coal—The Formation of Clinkers—The Influence of Iron in the Coal on the Formation of Clinker—Apparatus for Gas Analysis.

The combustible elements in coal are carbon, hydrogen, and sulphur, the atmosphere furnishing the oxygen necessary to convert the carbon into one of the two following products:

FORMULA.	COMBUSTION.	PRODUCT.
Carbonic acid,.....CO ₂	complete,	incombustible.
Carbonic oxide,.....CO	incomplete,	combustible.

The hydrogen unites with oxygen to form water H₂ O, in which the combustion is complete, and the product incombustible.

The nitrogen of the air remaining in the furnace after the union of the oxygen with the carbon and hydrogen, is incombustible, and acts as a dilutant of the gases in the furnace, having no affinity for any of the products of combustion.

The sulphur combines with oxygen to form sulphurous oxide SO₂, a colorless gas, with a suffocating odor; it is a non-supporter of combustion, instantly extinguish-

ing flame when brought within its influence. Sulphurous oxide, in absorbing the vapor of water, changes from

Sulphurous oxide, SO_2 to

Sulphurous acid, $\text{SO}_2, \text{H}_2\text{O}$

As there is almost always an excess of air supplied the furnace, often amounting to twice the quantity needed for combustion, this excess, also, becomes waste product, and acts as a dilutant of the furnace gases.

Smoke is regarded as a product of incomplete combustion. In its widest application it is made to include all the products of combustion issuing from the chimney. The use of the word is here restricted to the particles of solid carbon mingled with the escaping gases, or, it is the sooty portion only, of the escaping products. If the combustion of coal was perfect the escaping gases would be invisible. Very few analyses of smoke are on record, but our knowledge of the composition of coal, and of the products of the chemical union of oxygen with its several constituents, we may easily conjecture a qualitative composition of the escaping gases, though the precise quantities of each may be unknown.

When a charge of bituminous coal is thrown upon the fire, the effect of the heat is to detach small particles of coal from the surfaces most rapidly heated; these particles are generally very small, and in consequence weigh so little as to be easily carried over the fire and up the chimney by the mechanical agency of the draft alone. These particles of solid carbon reflect light, and

it is this property which renders them visible. If these particles of carbon were not present, the remaining products would be invisible. Whatever the quantity of coloring matter in the smoke as seen escaping from the chimney, it is to be regarded as so much fuel irrecoverably lost. The solid carbon passing off in this manner is often a considerable quantity, but the actual percentage is almost always overstated. Sometimes furnaces are so badly constructed that the chimneys leading from them are almost constantly pouring into the atmosphere a volume of gases, which, to judge from appearances merely, would seem to be half carbon, or, that half the coal fed into the furnace was passing off uncombined.

This mistaken notion as to the percentage of carbon present, has been so generally overrated, that devices for "burning smoke" have been offered by the score, often accompanied by the most absurd claims in regard to their efficiency as a "smoke consumer," and the great saving in coal to be effected in the event of their adoption.

What is needed is not so much a smoke consuming as a smoke preventing furnace, one which shall be so designed that any fuel rich in hydrocarbon, can be completely burned in the furnace proper, or within the chamber containing the incandescent fuel. This can be done only, by the admission of sufficient air to convert the carbon into carbonic acid and still maintain a high temperature in the furnace. The quantity of air required in the combustion chamber of a furnace is greater when a fresh charge of bituminous coal is thrown

upon the fire, than that needed a few minutes afterwards. If the high temperature of the furnace could be maintained at the same time a fresh charge is thrown upon the fire, the carbonic acid would entirely dissolve all the sooty carbon present in the flame and convert itself by this additional carbon into carbonic oxide, which may then by a proper supply of air be re-converted into carbonic acid by the addition of another equivalent of oxygen.

Smoke-prevention in a badly constructed furnace is attended with great practical difficulties; the chief one is the admission of cold air over the fire in a sufficient quantity to convert these minute particles of carbon into carbonic acid, and at the same time not lower the temperature of the furnace so as to affect the steam-producing power of the boiler, per pound of coal. In admitting air above the fuel, unless it can be supplied hot, it may prove a worse evil than the smoke itself, by lowering the temperature of the gases in the furnace to a point below which ignition is insured. In stationary boiler furnaces, in which much smoke is given off, perhaps the best thing to do is to lengthen the grate by carrying the bridge-wall farther back; the limit to this extension is a six-foot grate; in this manner increased grate area is obtained, and a slower rate of combustion. Now, by proper firing, this may be a means of largely reducing the escape of soot and carbon. The coal should not be spread evenly over the grate, but banked up near the door, and allowed to distill off the gaseous portions slowly, which, in passing over the bed

of incandescent fuel, are burned; after the charge of fuel has lost most of its volatile matter it may then be broken up and spread over the grate.

A fire-door, having perforations, or preferably an air inlet along its lower edge only, may prove of great service in admitting air where it is most needed.

In cases where the above is not practicable, a fan-blast may be used in connection with a closed ash-pit, and thus greatly intensify the action of the furnace; in which case the grate area may be reduced.

By either of these methods the quantity of smoke escaping may be reduced to within very narrow limits, if not entirely prevented; the latter, however, can scarcely be expected so long as coal is fed to the furnace in large lumps, and in considerable quantities, at long intervals.

SULPHUR A CAUSE OF CORROSION IN BOILERS.

There exists in France a commission whose special duty it is to look after boilers, and to try and find out the causes of accidents. A report was made to this commission after a thorough examination by M. Hanet-Clery, a mining engineer-in-chief, on the corrosion of steam boilers by the action of sulphuric acid. The commission had its attention drawn to the explosion of two steam boilers, one at a colliery in the Nièvre, the other at the Ougree iron works, in Belgium, and which were attributed to the destructive effect on the metal in consequence of the presence of sulphuric acid in deposits left by the smoke on certain parts of the sides of the

boiler. Other facts, or supposed facts, of like import appeared, and the subject was brought before the scientific and industrial world in the *Annales des Mines et des Ponts et Chaussees*, the problem being whether, under given conditions, the sulphurous acid of the smoke was turned into sulphuric acid, and the report of M. Hanet-Clery is one of the results (25).

“As regards the two accidents already referred to:

“1. The one which happened at the colliery occurred under the following circumstances: The boiler which burst was cylindrical, the fire being placed exactly beneath, and a superheater, from the cylindrical boiler by a brick arch, which nearly touched the upper part of the superheater. The latter was torn wide open in front, to the right of the strip which covered a longitudinal joint of two plates of iron, and then perpendicularly to the end on both sides.

“The thickness of the iron at the part which gave way first had originally been twelve millimeters, or half an inch nearly, but it had been reduced to 1.7 millimeter, and consequently totally incapable of supporting the pressure of six kilograms, under which the boiler worked. The destruction of the iron was all on the exterior, and extended—though not equally—over the upper end on the side not exposed. The mischief had all occurred in five years.

“M. Douville, a mining engineer, attributed it to the corrosive action of oxygen and sulphurous acid, contained in the products of combustion in the presence of water coming from a fissure in the boiler above, which,

having traversed the brick vaulting, fell on the re-heater, wetting the upper part, which was relatively cold, being situated at the extremity of the circuit of smoke, and close to the point where the feed-water arrived, and he remarked that the water vapor contained in the smoke was liable to condense there, and the effect of this condensation might be added to that of the infiltration, and favor the oxidation of the sulphurous acid into sulphuric acid; the water from the boiler concentrating itself chiefly along the edge of the cover-plate over the joint of the two plates, which prevented it descending. It would thus moisten the deposits in this part, which the form of the brick work prevented being regularly cleaned, and thus favored oxidation of the sulphurous acid in sulphuric acid on the surface of the metal. M. Douville found large scales of oxide of iron on the corroded parts, and also sulphur in some form of combination.

"2. The accident at the Ougree works presented more conclusive evidence; in this case, sulphuric acid was actually found in a free state, as well as in the form of sulphate of iron. The following are the circumstances of this case: The boiler was horizontal and cylindrical, with two water tubes below, and it was heated by the flames of the puddling furnaces. These flames at once enveloped one of the tubes and half the lower part of the boiler itself, and, making the circuit, heated the other half and second tube. The tube to the right of which the flames debouched was torn open in much the same manner as the superheater in the former

case; the fracture, taking two courses perpendicularly, one in the iron plate itself, the other along a riveted seam. The thickness of the iron was reduced to about one millimeter (one twenty-fifth of an inch), at the edges of the first rent. The corrosion was all exterior.

“Two samples of the soot, etc., left by the smoke in the parts destroyed were analyzed; they gave sulphate of iron between fifty-two and fifty-three per cent., and free sulphuric acid in one sample 1.42, and the other nearly twelve per cent. Soot from other parts also contained sulphuric acid, but not enough to have any sensible result on the iron.

“The action is thus explained: the soot, etc., is deposited during the working of the puddling furnaces in an entirely dry state, but when the fires are put out, the air, loaded with humidity, enters and converts the soot into a paste; the oxidation of the sulphurous acid then occurs, and the iron is in the best condition to be attacked. The corrosive action is thus going on all the time the boiler is not in work, in parts that could not be cleaned out, while no such action occurred where the soot had been cleared away.

“3. Examples of exterior corrosion by condensation of steam suspended in the smoke on the colder portions of boilers were pointed out by M. Meunier Dollfus some years since, and published; one of these cases was observed at the works of M. Charles Kestner, at Thaun.

“The works contained two cylindrical boilers with three tubes, and between them, in the same brick-work,

six re-heaters arranged in pairs on three stages. The flames circulated under the three tubes, twice around the boiler itself, and then in the three stages of the re-heater from above downwards. The feed-water traversed in the opposite direction. Generally only one of these boilers was used at a time, working night and day, but less actively at night.

“In an experiment, when the feed-water arrives at a temperature of 68° Fahr., the water of the first re-heater below only marked 86° Fahr. on issuing, and that of the third re-heater at 122° Fahr. On the other hand, the temperature of the smoke and gases at the issue of the third re-heater did not exceed 302° Fahr. in the day and 212° Fahr. at night. At the end of two years’ working, under the above conditions, the re-heaters were already attacked, and at the end of six years, although the iron was of excellent quality, they were so reduced that they had to be replaced. The corrosion took place on the colder portions of the re-heaters, and it was found that the first cause was the sulphurous acids contained in the condensed steam deposited by the smoke, and in the presence of air and of these acid waters, oxidation of the iron readily occurred, with the subsequent production of sulphate of iron.

“4. Observations have also been made on this cause of destruction of boilers, by M. Cornut, Engineer of the Association of the Proprietors of Steam Apparatus of the North of France, at Lille. He often observed exterior corrosions, which he attributed to the action of smoke, and which he found absolutely confined to those

parts of the iron which were wetted by infiltration or accident.

“5. Resuming the facts stated above, the transformation of sulphurous into sulphuric acid, under the action of water, or steam and air, in presence of a metal is not new. This property of sulphurous acid has even been employed practically in treating certain minerals, and in purifying the neighborhood of certain metallurgical establishments. We may mention as a notable instance, the process of M. Lamine, for the manufacture of sulphate of alumina at Ampain, in Belgium, and the treatment of certain oxides of copper on the banks of the Rhine. Such applications as these, not of recent date, should have awakened engineers to the possibility of the destruction of the iron boilers by a like action, but such was not the case, and it remains to be noted that if the fact is now well known, the subject requires to be most carefully studied in all its details, some of which can not fail to be of practical importance.”

Conclusion—The whole may be summed up as follows: In the matters deposited on the plates of boilers, at a certain distance from the fire, and which are rendered humid by any accidental cause, the sulphurous acid carried forward by the combustion gases, attack the iron by the formation of sulphate of iron.

The attack may occur while the boiler is heated through an escape of water, from the boiler itself, by infiltration through the brick work, or by the condensation of steam in the flames and smoke in contact with

iron plate relatively cold. It may also occur when the boiler is not in use, by means of the penetration of the air into the flues.

The diverse origin of the corrosive action points out the nature of the precautions to be taken to obviate the destruction, except as applies to the condensation of the vapors, on which subject many arrangements have been recommended, but have not yet obtained the sanction of experience.

The precautions, alluded to above, are only such as should be taken in ordinary practice for the preservation of apparatus; that is to say, careful design and construction, and systematic and complete cleansing.

ASHES AND CLINKER

Every variety of mineral fuel contains more or less incombustible matter called ashes. The presence of this incombustible substance in coal is due in part to the inorganic matter contained in the plants of which the coal is formed, and partly by the earthy matter in the drift of the coal period. The percentage of ash varies considerably for different coals, but it is generally less in the anthracite than in the bituminous varieties.

Upon analysis coal ashes are found to consist principally of silica, alumina, lime, and oxide and bisulphide of iron. The nature and color of ashes are greatly modified by the proportions in which the above substances are united in the composition. In the following analysis, as in all analyses of coal ashes, silica and alumina predominate.

Analysis of ashes of Pennsylvania anthracite coal,
by Professor W. R. Johnson:

Silica.....	53.60
Alumina.....	36.69
Sesquioxide of iron.....	5.59
Lime.....	2.86
Magnesia	1.08
Oxide of Manganese.....	.19
	<hr/>
	100.01

The next analysis is from the geological survey of
Ohio:

Bituminous coal. Percentage of ash, 5.15.

Silica	58.75
Alumina.....	35.30
Sesquioxide of iron.....	2.09
Lime.....	1.20
Magnesia.....	0.68
Potash and soda.....	1.08
Phosphoric acid.....	0.13
Sulphuric acid.....	0.24
Sulphur, combined	0.41
	<hr/>
	99.88

An ordinary sample of block coal, from Clay county,
Indiana, was analyzed by Professor E. T. Cox, and
found to contain,

Fixed carbon.....	56.50
Gas.....	32.50
Water.....	8.50
Ash.....	2.50
	<hr/>
	100.00

Specific gravity, 1.285	
Coke: Not swollen, laminated, lusterless.	
<i>Composition of Ash:</i> Color, white.	
Iron, sesquioxide.....	.82
Alumina.....	1.20
Silica, lime, magnesia, etc.....	.48
	<hr/>
	2.50

Of the sulphur present in the coal,

.947 was in combination with iron.

.483 with other constituents.

1.430 per cent. of sulphur in the sample.

Nearly every variety of coal contains more or less iron-pyrites; this is the probable source of the oxide of iron in the ashes; the greater part of the sulphur being expelled by heat, its equivalent of oxygen unites with the iron, and with which hydrogen also combines, forming the sesquioxide of iron of the analysis. The amount of oxide of iron, present in ashes, is one of great importance, especially as it unites with the potash, soda, lime and silica, also present, to form clinker. The presence of iron in ashes, when in any considerable quantity, may be detected, without analysis, by the red color imparted to them. When the amount of iron is very small, or not sufficient to tinge the ashes, they are then usually white; so the terms *red-ash* and *white-ash* may be a sort of index by which we may judge of the probable nature of the ashes, whether they will clinker in the fire or not. The intensity of the red color, taken in connection with the amount of ashes in coal, may

also serve as an indication of the proportion of sulphur existing in the state of pyrites.

The particular objection to the combination and fusing of the silica, lime, potash, soda, etc., in the ashes of the coal into a vitreous mass is, that unless the greatest care is exercised, it will accumulate upon the grate-bars in sufficient quantity as to exclude the passage of the air needed for combustion, and thus lower the temperature of the furnace.

These several constituents are variable in their nature, and by the forms they take under different intensities of combustion, much affect the efficiency of the coals to which they belong (23). Being differently fusible themselves, and affecting differently the fusion of each other, no two of the earths, alkalies, or metallic oxides of the ashes, but differ in their agency when subjected to an elevated heat, and their mutual reactions are moreover changed, as the temperatures are changed to which they are exposed. It hence arises that the residue from many coals melts to a large extent, under no very intense combustion, into various descriptions of hard semi-vitreous slags; others yield a less stony clinker; and some again, at a far more elevated heat, result only in a partially agglutinated, spongy, open cinder, or even in a pulverulent or flaky ash. There are, perhaps, no coals whose ashes, when exposed to the extremest heats procurable by artificial blasts, will not soften to a cohering cinder, or even melt in part into a stony clinker; but as the tendencies to these several degrees of fusion are very various, it proves to be a distinction affecting the prac-

tical value of coals, which is of the utmost importance. In domestic consumption, where the heat of combustion is comparatively moderate, the quantity rather than the quality or fusibility of the ashes is the point of greatest consideration; but where an excessive and melting heat is required, as in many modes of generating steam, the practicability of employing a coal at all will oftentimes be determined by this one quality of clinkering of the ashes. In all such circumstances, those coals are best the ashes of which are of a nearly pure white, and which, with large amounts of silica and alumina in their composition, contain little or no alkali, nor any lime, nor oxide of iron. Of this character, are the earthy residue of the best white-ash anthracites, of Pennsylvania, and, in an eminent degree, the ashes of some of the semi-anthracites.

In general, it requires a high temperature to fuse these ingredients when taken by themselves, but the presence of the oxide of iron tends to lower the point of fusion, and thus increases the difficulty.

The grate bars recommended for any coal, the ashes of which are liable to clinker, are any of those forms which may, while in position and in use, be either shaken, tilted, or revolved without injuriously breaking up the fire.

APPARATUS FOR GAS ANALYSIS (19).

As a rule, gaseous agents hold a very important position in technical chemistry, whether atmospheric air be employed in ordinary cases, or under circumstances

in which the employment of other gases is desirable for chemical analysis. In most of the latter cases special apparatus is desirable for the production of such gases. If we take metallurgical analysis, for example, as a branch of technical chemistry, we shall frequently find that remarkable and crucial differences occur according to the gas employed. The question of their quantity frequently becomes of importance in regard to first indications for qualitative and quantitative analysis, as an instance of which may be mentioned the free combustion of any form of carbon, supposing the amount of air present to have been entirely utilized, taking at the same time the relation of the weight of air to that of consumed carbon. But in all such cases great uncertainty exists in the exact estimation of such relations.

Despite the advantage of its study, that of gaseous analysis has scarcely yet found its proper position in technical chemistry, although the latter branch of science has of late made very rapid strides. The reason of this may be partly explained on the ground that there is much difficulty in manipulating with all gases, resulting from the delicacy of the apparatus employed in the laboratory, and the usual slowness of such operations.

Although comparatively few gases are met with in technological operations, yet their action predominates over almost any other agent, and consequently it is desirable to arrange such an apparatus more simple than those usually employed in laboratories, without the use of the pneumatic trough of water or mercury (both frequently inconvenient), nor requiring barometrical or

thermometric corrections hitherto considered indispensable. It is desirable, in fact, to present such an arrangement as shall be readily available for the use of ordinary intelligent workmen, so as to furnish not only ready but comparatively trustworthy indications.

For the purpose just referred to, M. De H. Orsat, of Paris, has suggested the apparatus here illustrated.

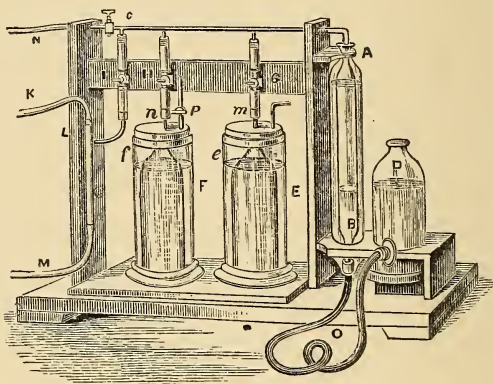


FIGURE 4.

“The apparatus consists essentially as a graduated pipe, *A B*, placed in a receiver filled with water, intended to preserve a constant temperature, a most important point in gas analysis. This graduated tube communicates at *A* with a horizontal capillary tube, furnished with a stop-cock, *C*, through which the gas passes into the measuring apparatus. The lower portion of the measuring arrangement is connected by an India rubber tube, *O*, to a gas jar, *D*, by means of an opening at the bottom; this jar being partly filled with water, the water in this jar may be lowered by sucking

out, or raised by blowing into it. The horizontal tube is connected by two branches furnished with two stop-cocks, *G* and *H*, with two bell-glasses placed in the eprouvettes, *E* and *F*, which contain the liquids intended to absorb the gases under examination or use. The first eprouvette, *E*, contains a solution of caustic potass. The bell-glass is entirely filled with small tubes of glass, open at both ends, and intended by capillary and other action to facilitate, as far as possible, the rapid absorption of the gas in the bell-glasses.

“The second eprouvette, *F*, contains an ammoniacal solution of chloride of ammonium (sal-ammoniac). The interior of the second bell-glass is filled with metal foil, consisting of copper, in repeated coils, so that at the same time oxygen shall be absorbed, oxide of carbon, in the presence of the saline solution, by chemical action, combining with the physical action of the tubes in the first eprouvette.

“For the sake of safety, a fourth stop-cock allows the escape of gas, which would otherwise remain in the apparatus. If the tube *N*, which brings the gas, has great length, it is easily cleaned by the arrangement, marked *K L M*, by water. It is sufficient to send a few decimeters* of water by the tube, *K M*, to produce an up-draft in *L*, to act as a balance to the gas in *N*. A litre of water, or say, a quart, English, is sufficient to effect this in a tube of four millimeters (0.15 in.) in diameter. By connections with the tube *N*, by India rubber piping, any apparatus employed in gas analysis

* A decimeter = 3.94 inches.

may be employed, and by very simple arrangements the outer apparatus may be applied for any of the objects hereafter named.

“The explanation of the use of the apparatus will be better understood by the following remarks:

“The first bell-glass receives gases absorbable by means of a solution of caustic potass; the second receives those which, being not absorbed by the first, are absorbable by means of a solution of copper. For example, in the ordinary combustion analysis, the first absorbs carbonic acid, and the second oxygen and carbonic oxide.

“In the ordinary state of combustion, both of these gases are given off, and some inconvenience might be supposed to arise from the fact, but the difficulty is more apparent than real.

“They are easily separated on account of their chemical individuality.

“In certain cases, it happens that carbonic oxide may remain with oxygen, but even in this case an approximative result of their proportions may be obtained, when the combustible matter does not afford free oxygen nor hydrocarbons. Practically, the oxygen afforded by the atmosphere does not change its volume by aiding to produce carbonic acid, while its volume is doubled by producing carbonic oxide. It, therefore, becomes a simple question of calculation to determine the nitrogen in the measured tube, and any other determination depending on measurement in the absence of absorption.

“In certain cases the addition of a third bell-glass would be desirable, especially in the event of the respect-

ive presence of oxygen and carbonic oxide requiring to be determined. The third glass should then be supplied with pyrogallate of potash, or stick of phosphorus. Sulphurous acid may also be determined by the apparatus, also hydrosulphuric acid (sulphureted hydrogen), and chlorine. In special cases the apparatus might be employed for estimating gases which present themselves in a separate form; sulphurous acid, for example, in the presence of carbonic acid, may be estimated by a solution of potass in sulphuric acid (and water), or by the permanganate of potash. When gases very soluble in water are to be examined, as, for example, sulphurous acid, there should be a substitute of glycerine in the bottle or flask, *D*, in place of water."

The value of this apparatus largely rests on the fact that it may be placed in the hands of an ordinary workman for qualitative analysis to control his operations. At the same time its indication may be controlled by very simple arrangements, so that the manager may notice the indications afforded by each apparatus, without the knowledge of those using it. It is applicable to a large variety of purposes, as, for example, the estimation of the gaseous products of reverberatory furnaces, puddling furnaces, the Bessemer, and Danks arrangements for dealing with pig-iron, the production of carbonic acid in lime-burning, sugar works; the manufacture of alkaline carbonates, wine, beer, and vinegar production, with an immense variety of technical and other purposes.

CHAPTER IX.

THERMAL POWER OF FUELS.

Heat Developed by Chemical Action—Favre and Silberman's Apparatus—Units of Heat Evolved by Elemental Combustion—Heat Developed by the Combustion of Coal—Allotropic States of Carbon—Proximate Constitution of Coal—Experiments of Scheurer-Kestner and Meunier-Dollfus on the Calorific Power of Coal—Thompson's Calorimeter—Manner of Conducting Experiments—Evaporative Power of Coal—Object in Reducing Evaporation to, from and at 212° Fahr.

The total heat of any combustible may be calculated, if its proximate or elementary analysis is known, by means of data analogous to that furnished by Favre and Silberman, or it may be determined by means of a calorimeter, similar to that of Thompson, described in this chapter.

HEAT DEVELOPED BY CHEMICAL ACTION.

The apparatus used by Favre and Silberman for measuring the heat evolved by the combustion of various substances in oxygen gas is represented, with the omission of minor details (13), in figure 5. *C* is a vessel of gilt brass plate, immersed in a water-calorimeter, *A A*, of silvered copper plate, and the latter is enclosed in an outer vessel, *B B*, the space between *A* and *B* being filled with swan-down, to prevent the escape of heat from the water in *A*. The vessels *A* and *B* are closed with lids having apertures for the insertion of tubes and thermometers. The combustions are per-

formed in the vessel *C*, into which oxygen is introduced through the tube, *c d*, and the gaseous products of the combustion escape by the tube, *e f g h*, the lower part of which is bent into numerous coils, to facilitate, as much as possible, the transmission of the heat of these gases

to the water in the calorimeter. The extremity, *h*, of this tube is connected with a gasometer, or with an absorbing apparatus. To insure uniformity of temperature in the water, a flat ring of metal, *i i*, is moved up and down by means of the rod, *K i*. Combustible gases were introduced into the vessel *C*, by means of fine tubes, the gas being previously set on fire at the aperture. Solid

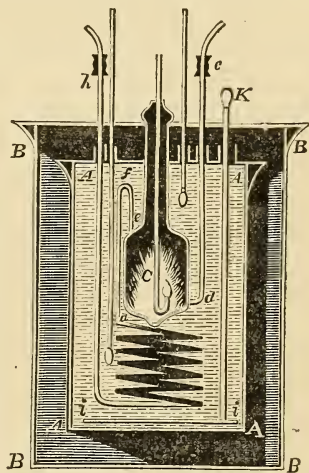


FIGURE 5.

bodies were attached to fine platinum wires suspended from the lid of the calorimeter; the liquids were burned in small capsules, or in lamps with asbestos wicks; charcoal was disposed in a layer on a sieve-formed bottom, through the openings of which the oxygen had access to it. The heat evolved was measured by the rise of temperature of the known quantity of water in the calorimeter.

TABLE XIX.

SHOWING THE TOTAL QUANTITIES OF HEAT EVOLVED BY THE COMPLETE COMBUSTION OF ONE POUND OF COMBUSTIBLE WITH OXYGEN; ADAPTED FROM THE RESULTS OBTAINED BY FAVRE AND SILBERMAN. THE UNIT OF WEIGHT IN THIS TABLE BEING ONE POUND, AND THE UNIT OF TEMPERATURE ONE DEGREE FAHR. (FROM 39° TO 40°).

SUBSTANCE.	FORMULA.	PRODUCT.	UNITS OF HEAT
GASES.			
Hydrogen.....	H	H ₂ O	62,032
Carbonic oxide.....	CO	CO ₂	4,325
Marsh gas.....	CH ₄	CO ₂ & H ₂ O	23,513
Olefiant gas.....	C ₂ H ₄	CO ₂ & H ₂ O	21,343
LIQUIDS.			
Oil of turpentine.....	C ₁₀ H ₁₆	CO ₂ & H ₂ O	19,533
Alcohol.....	C ₂ H ₅ O	CO ₂ & H ₂ O	12,931
Spermaceti (solid).....	C ₃₂ H ₆₄ O ₂	CO ₂ & H ₂ O	18,616
Sulphate of carbon.....	CS ₂	CO ₂ & SO ₂	6,122
SOLIDS.			
Carbon (wood charcoal).....	C	$\left\{ \begin{array}{l} \text{CO} \\ \text{CO}_2 \end{array} \right.$	$\left\{ \begin{array}{l} 4,451 \\ 14,544 \end{array} \right.$
Gas coke .....	.....	.....	14,485
Graphite from blast furnaces .....	.....	.....	13,972
Native Graphite.....	.....	.....	14,035
Sulphur (native).....	S	SO ₂	4,048
Phosphorus (observed by Andrews).....	P	P ₂ O ₅	10,715

HEAT DEVELOPED BY THE COMBUSTION OF COAL.

This may be determined theoretically by taking the units of heat evolved by each element in the coal separ-

ately—allowing certain deductions—and adding them together. This requires then, an elementary analysis to begin with. Assuming, for example, that a certain sample of coal, weighing one pound, is analyzed, and is found to contain,

Carbon.....	.81
Hydrogen.....	.05
Oxygen.....	.04
Nitrogen, ash, etc.....	.10
	<hr/> 1.00

and that the sulphur and other impurities in the coal be disregarded, we proceed to estimate its calorific power in this way:

	UNITS.	PER CENT.
Carbon.....	14,500	$\times .81 = 11,745$

units of heat in the carbon.

Since oxygen and hydrogen unite to form water, the whole of the oxygen must be deducted, together with its equivalent of hydrogen, before we can determine the calorific power of the latter, for the available hydrogen in the coal is only that above the quantity required to unite with oxygen, as stated above.

Oxygen unites with $\frac{1}{8}$ of its own weight of hydrogen to form water; and,

$$\frac{1}{8} \text{ of } \frac{4}{100} = \frac{4}{800} = .005$$

pound of hydrogen neutralized by the presence of oxygen in the coal, leaving

$$.05 - .005 = .045$$

pound of available hydrogen; then, proceeding as before:

	UNITS.	PER CENT.
Hydrogen.....	$62,032 \times .045 =$	2,791. units.

adding the

Carbon	$14,500 \times .81 =$	11,745. units.
Total		14,536.

units of heat in one pound of coal of the composition assumed.

This is called the *theoretical calorific power* of coal.

The nitrogen and ash being inert, are simply dilutants, and no account is taken of them.

This appears, at first sight, a very simple and easy method of determining the calorific power of coal, but it is open to serious objections; one is, the elementary analysis demanded as a starting point; another, is the uncertain value of carbon.

The following table is compiled from the researches of Favre and Silberman

TABLE XX.

VARIETIES OF CARBON.	UNITS OF HEAT.
Diamond.....	13,986
Graphite—artificial.....	13,972
Graphite—native.....	14,035
Carbon from gas-retorts.....	14,485
Charcoal from wood.....	14,544

These substances, it may be remarked, are practically elemental, yet, the difference between the two extremes are five hundred and fifty-eight heat units.

How much of this difference is due to the allotropic condition of the carbon is not easily stated; it is possible, and altogether probable that it has much to do with it.

It might be said that as diamonds, graphite, and gas carbon are not employed as fuel, it is of little consequence what difference there may be between them. This would appear to the superficial observer as a "practical" truth, but it is not so. It must be remembered these are not compounds of carbon, but pure carbon. If the theoretical power of carbon is an uncertain quantity, then, a guess is as good as a calculation.

The various kinds of coal found in this country, passing through an innumerable series of gradations, from the least cohesive of the bituminous varieties, to the hard crystalline Lehigh anthracite, adds emphasis to the question instead of waiving it.

Assuming the calorific power of coke to be known, it is desirable to know whether the volatile portion of the coal yields the calorific power ascribed to it by calculating the elements separately, and adding them together; also, whether the sum of the heat units of the coke and volatile matter is more or less than the units of heat given off by the coal during the actual burning. Various calorimeters have been devised to ascertain, if possible, a close approximation to the actual calorific power of any given sample of coal without undergoing any analysis whatever.

This seems all the more desirable as the proximate constitution of coal is wholly unknown (20); we are ignorant whether force is liberated or absorbed during the decomposition—previously to, or at, the moment of combustion—of the various compounds of carbon, hydrogen and oxygen, of which the organic part of coal must be composed. Again, the hydrogen and oxygen are present in the solid state, and we are unable to determine what amount of force may be absorbed during their conversion into the gaseous state.

EXPERIMENTS ON THE CALORIFIC POWER OF COAL.

M. M. Scheurer-Kestner and Charles Meunier-Dollfus, have, within a few years past, made a special study of different coals with reference to their calorific power, making use of a modified form of the Favre and Silberman calorimeter, described on page 179 in this volume; the modifications were such that the carbonic acid produced on combustion was cooled with great rapidity, whereby the quantity of carbonic oxide formed was much reduced. It has not been found possible to prevent the formation of some carbonic oxide during the combustion of carbon, even under the most favorable conditions, but the amount produced in each experiment can be accurately determined by passing the products of combustion first through a solution of potash, which absorbs the carbonic acid, and afterward through a tube containing black oxide of copper heated to redness. By this means carbonic oxide can be converted into car-

bonic acid, which may be collected in a solution of potash and weighed.

For the sake of comparing the experimental with the theoretical values of the coals as deduced from their composition in the manner before described, they reduced their experimental results, and calculated them as though the coals had consisted wholly of the organic constituents, excluding the ash and the hygroscopic water. They made corrections for the carbon, which, in their experiments in the calorimeter, was retained in the ash, and also for the hydrogen and carbonic oxide which escaped combustion; but they appear to have taken no account of the sulphur in the state of sulphide, which all coal contains, and which would, in greater or less degree, according to its quantity, add to the amount of heat produced in the calorimeter.

TABLE XXI.
SHOWING THE EXPERIMENTAL AND THEORETICAL CALORIFIC POWERS OF DIFFERENT COALS, SELECTED FROM THE
RESULTS OF SCHEURER-KESTNER AND MEUNIER-DOLLFUS (20).

NUMBER.	LOCALITY.	DESCRIPTION OF COAL.	CALORIFIC POWER CALCULATED ON THE DRY COAL, FREE FROM ASH.		PERCENTAGE COMPOSITION OF THE COAL EXCLUSIVE OF ASH AND WATER.			COKE, PERCENT, CALCULATED ON THE DRY COAL, FREE FROM ASH.
			EXPERIMENTAL.	THEORETICAL.	CARBON.	HYDROGEN.	OXYGEN AND NITROGEN.	
1	} Manosque, Basses..... } Alps.....	Lignite	12,584	10,408	66.31	4.85	28.84	46.76
2		Lignite	13,253	11,759	70.57	5.44	23.99	47.55
3		(Not stated).....	14,787	12,701	76.87	4.68	18.45	59.49
4	} Duttweiler, Saarbruck..... } Creusot	(Not stated).....	15,703	14,168	83.82	4.60	11.58	63.58
5		Caking coal.....	17,320	15,091	88.48	4.41	7.11	80.42
6	} Creusot	Non-caking coal...	16,727	15,453	90.79	4.24	4.97	84.12
7		Anthracite	17,021	15,395	92.36	3.66	3.98	88.15

From an inspection of the table, it will be seen, that in every case the experimental calorific power of the coal considerably exceeds the calculated result, and that coals with nearly the same percentage composition, so far as regards organic constituents, may differ widely in calorific power.

TABLE XXII.

SHOWING THE EXPERIMENTAL CALORIFIC POWER OF DIFFERENT COALS AND LIGNITES AS OBSERVED BY SCHEURER-KESTNER AND MEUNIER-DOLLFUS.

COMBUSTIBLE.	GASEOUS ELEMENTS.			HEAT OF COMBUSTION OF ONE POUND PURE (OBSERVED).
	CARBON.	HYDROGEN.	OXYGEN AND NITROGEN.	
COAL.	PER CENT.	PER CENT.	PER CENT.	UNITS.
Ronchamp, three samples	88.59	4.69	6.72	16,416
Saarbruck, seven samples.....	81.10	4.75	14.15	15,320
Creusot, four samples.....	90.60	4.10	5.30	16,994
Blanzy—Montceau	78.58	5.23	16.19	14,985
Blanzy—Anthracitic	87.02	4.72	8.26	16,400
Angin	84.45	4.21	11.32	16,663
Denain	83.94	4.43	11.63	16,290
English—Bwlf.....	91.08	3.83	5.09	15,804
English—Powell-Duffryn.....	92.49	4.04	3.47	16,108
Russian—Grouchevski Anthracite	96.66	1.35	1.99	14,866
Russian—Miouchi, Bituminous.....	91.45	4.50	4.05	15,651
Russian—Goloubofski, flaming ..	82.67	5.07	12.26	14,438
LIGNITES.				
Rocherblea	72.98	4.04	22.98	11,670
Bohemia, Bituminous.....	76.58	8.27	15.15	14,263
Russian, Toula	73.72	6.09	20.19	13,837
Lignite, passing to fossil wood.....	66.51	4.72	28.77	11,444
Fossil wood, passing to lignite.....	67.60	4.55	27.85	11,360

The fuel is assumed to be dry and pure—without any ash.

THOMPSON'S CALORIMETER.

The object of this instrument is to give approximately, by means of a simple experiment, the *theoretical* evaporative power of any fuel submitted to investigation (20).

“It consists of a glass cylinder, *A*, closed at the lower end only, to contain a given weight of water.

“*B* is a cylindrical copper vessel, called the *condenser*, closed at one end with a copper cover, in which is fixed a metal tube *C*, communicating with the interior of the vessel *B*, and fitted at its upper extremity with a stop-cock. The other end of *B* is open, and it is perforated near the open end by a series of holes, *bb*.

“*D* is a metal base upon which *B* is fixed by means of three springs, which are attached to *D*, and press against the internal surface of *B*, but which are omitted from the wood cut for the sake of clearness. A series of holes is arranged round the circumference of *D* to facilitate raising the apparatus through the water.

“*E* is a copper cylinder, called the *furnace*, closed at the lower end only, which fits into a metal ring or seat on the center of *D*.

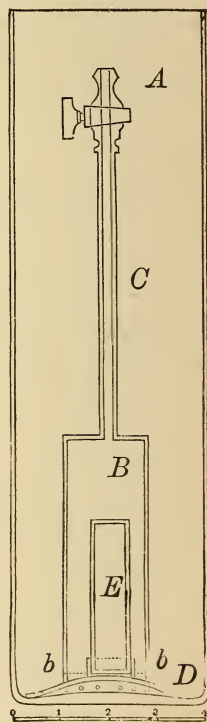


FIGURE 6.
Scale one-fourth full size.

“The manner in which results are obtained is as follows: A known weight of the fuel is burnt by means of chlorate of potash and nitre at the bottom of a vessel containing a known weight of water; the heat produced by the combustion of the fuel is communicated to the water, and from the rise in temperature of the latter is calculated the number of parts of water which the combustion of one part of the fuel will raise one degree in temperature: this number being divided by the latent heat of steam (537 or 967 units, according as the centigrade or Fahrenheit scale is employed), gives the evaporative power of the fuel, *i. e.*, the number of pounds of water (supposed to pre-exist at the boiling point) which one pound of the fuel is theoretically capable of evaporating.

“In the instrument, as constructed by the manufacturer, it is intended that thirty grains of the fuel should be burnt, and that 29,010 grains (or nine hundred and thirty-seven times this weight) of water should be employed; hence the rise in the temperature of the water, expressed in degrees Fahrenheit, is equal to the number of pounds of water which one pound of the fuel theoretically will evaporate; but ten per cent. is directed to be added to this number, as a correction for the quantity of heat absorbed by the apparatus itself, and consequently not expended in raising the temperature of the water.

“In addition, the gaseous products of combustion generally escape from the surface of the water whilst sensibly warm. Whether this loss of heat is covered by

the above correction, I am unable to state; that it is not unimportant, has been proved, in my laboratory, by enclosing the lower part of the condenser within a large metallic cylinder, perforated all over with small holes, so that the escape of gases from the water was retarded when the experimental results obtained were notably higher. Thus, in comparative experiments upon a Welsh steam coal, it was found that its theoretical evaporative power was raised from 14.41 to 14.96 pounds of water, by enclosing the condenser in the manner described. The colder the water, the smaller will be this loss of heat, owing to the gases being more thoroughly cooled.

"The experiment is conducted in the following manner: Thirty grains of finely-powdered fuel is intimately mixed with from ten to twelve times its weight of a perfectly dry mixture of three parts of chlorate of potash and one part of nitre; the resulting mixture, which, for the sake of distinction, may be called the *fuel-mixture*, is introduced into the furnace, *E*, and carefully pressed or shaken down. The end of a slow fuse, about half an inch long, is next inserted in a small hole made in the top of the fuel-mixture, and is fixed there by pressing the latter around it; the furnace is then placed in its seat on the metal base, *D*, the fuse lighted, and the condenser, *B*, with its stop-cock shut, fixed over the furnace.

"The cylinder, *A*, is previously charged with 29,010 grains of water, the temperature of which must be recorded, and the apparatus is now quickly submerged

in it. The fuse ignites the fuel-mixture, and when the combustion is finished (indicated by the cessation of the bubbles of gas, produced by the combustion, which rise through the water), the stop-cock is opened, and the water enters the condenser by the holes, *bb*.

“By moving the condenser up and down, the water is thoroughly mixed and acquires a uniform temperature, which is then recorded. By adding ten per cent. to the number of degrees Fahr. which the water has risen in temperature, the theoretical evaporative power of the coal is at once approximately determined.

“The furnace shown in figure 6 is intended to be used when bituminous coals are to be operated upon; but in experimenting on coke, anthracite and other difficult combustible fuels, a wider and shorter furnace is preferred, and the fuel mixture should not be pressed down.”

EVAPORATIVE POWER OF COAL—By this is meant the number of pounds of water, which, under certain conditions, are capable of being evaporated per pound of coal. It is essential to the obtaining of accurate results, that the temperature of the feed water and the temperature of evaporation should both be ascertained, and the total heat per pound of water computed. That total heat being divided by 966, the latent heat of evaporation of a pound of water at 212° , gives a *multiplier*, by which the weight of water actually evaporated by each pound of fuel is to be multiplied, to reduce it to the *equivalent evaporation from and at 212°* ; that is, the weight

of water which would have been evaporated by each pound of fuel, had the water been both supplied and evaporated at the boiling point corresponding to the mean atmospheric pressure.

The weight of water so calculated is called the *evaporative power* of the fuel.

The object of reducing evaporative results in practice to equivalent evaporation from and at 212° , is to afford an intelligible basis of comparison between different kinds of fuel.

To make such a comparison it is necessary to know the pressure and temperature of the steam; the temperature of the feed water; the number of pounds of coal burned on the grate (deducting the ashes, if the net combustible is desired); and the number of pounds of water evaporated in a given time. From these last two items the ratio of coal, or net combustible, to evaporation can easily be determined by dividing the pounds of water evaporated, by the pounds of coal burned in an hour, a day, or any other given time.

EXAMPLE—A boiler evaporating eight pounds of water per pound of coal (net), the temperature of the feed water being 85° Fahr., and the pressure of steam in the boiler seventy-five pounds per square inch, above the atmosphere; what is the equivalent evaporation per pound of coal (net) at atmospheric pressure from and at 212° ?

The total heat required to generate one pound of steam from water at 32° Fahr., under a constant pressure

of seventy-five pounds per square inch is 1176 units of heat. The water entering the boiler at a temperature of 85° instead of 32° , there is a gain of $85 - 32 = 53$ degrees. Then,

$$1176 - 53 = 1123 \text{ units of heat.}$$

The units of heat required to convert one pound of water at 212° into steam, at atmospheric pressure, is 966. Then,

$$1123 \div 966 = 1.16, \text{ the multiplier.}$$

$$\begin{array}{r} 1.16 \\ 8 \text{ pounds of coal.} \\ \hline 9.28 = \end{array}$$

the equivalent evaporation per pound of coal (net), at atmospheric pressure, from and at a temperature of 212° .

SECOND METHOD—When the total heat of combustion of one pound of combustible is known.

In this case, the equivalent evaporative power of the combustible at atmospheric pressure, from and at a temperature of 212° , may be determined by dividing the number of heat units of the combustible by 966, the number of heat units required to convert water at 212° into steam at atmospheric pressure.

EXAMPLE 1—What number of pounds of water, at 212° , will one pound of bituminous coal, having 13,624 heat units as its total heat of combustion, convert into steam at atmospheric pressure?

$$(14) \quad \frac{13,624}{966} = 14.1 \text{ pounds of water.}$$

EXAMPLE 2—The same as the preceding except the feed water to be at 64° instead of 212° ? Then,

$$212^{\circ} - 64^{\circ} = 148^{\circ} \text{ difference.}$$

$$966^{\circ} + 148^{\circ} = 1114^{\circ} \text{ the new divisor.}$$

$$\frac{13,624}{1114} = 12.23 \text{ pounds of water.}$$

And in this manner for any temperature between 32° and 212° .



CHAPTER X.

HEAT.

Theory of Heat—Mechanical Force—Chemical Action—Relation of Atomic Weights to Specific Heat—Specific Heat of Simple Gases—Specific Heat and Atomic Weight of Elementary Substances—Specific Heat—Specific Heat of Water in its Three States—Specific Heat of Fuels—Specific Heat of Gases—Latent Heat—Latent Heat of Fusion—Latent Heat of Evaporation—Mechanical Theory of Heat—Joule's Equivalent—Apparatus Employed by Joule—Unit of Heat.

The theory of heat now accepted is known as the *dynamical*, or the *mechanical theory*, and is so called because it is believed that heat and mechanical force are identical, and convertible one into the other.

The relation between heat and mechanical force is now expressed by a numerical equivalent, which is so nearly true that it serves to show not only the probable permanence of this theory, but indicates, also, that these relations are determined by a fixed numerical law.

From the vast number of experiments in the generation of heat by mechanical processes; by friction; by the arrest of motion, either gradually or by percussion; by the change in quantity of heat observed in the case of expansion, etc., has led investigators to the conclusion that heat is simply a *motion* of ultimate particles, and that the molecular structure of bodies has much to do with their capacities for heat; and, an increase or decrease of temperature is simply an increase or decrease of molecular motion.

As all chemical changes are either atomic or molecular, and as all differences in the temperature of bodies are due to the changes in their molecular condition, it would appear that chemical action, and heat, and mechanical force, should be mutually convertible. This is now a widely recognized truth.

Chemical changes are always attended by a change in the thermal conditions of the bodies acted upon, in which combinations as a rule, produce heat, while decompositions produce cold, or a disappearance of heat. The amount of heat any particular body is capable of giving off must be determined, as yet, experimentally. The researches of Favre and Silberman, Andrews, Thompson, Joule, and others, have given us a very close approximation to the dynamic value of heat, and the heating power of different fuels. The results of their investigations, so far as it affects the combustion of coal, are given elsewhere in this volume.

Relation of Atomic Weights to Specific Heat—In regard to the atomic weights and their relation to specific heat, it is a noteworthy fact, that as the specific heat increases the *atomic weight* diminishes, and *vice versa*; so that the product of the atomic weight and specific heat is, in almost all cases, a sensible constant quantity (30). The most important experiments on the specific heat of elastic fluids we owe to M. Regnault. He determined the quantities of heat necessary to raise equal volumes of them, through the same number of degrees. Calling the specific heat of water 1, here are some of the results of this invaluable investigation:

TABLE XXIII.
SPECIFIC HEAT OF SIMPLE GASES.

	SPECIFIC HEATS.	
	EQUAL WEIGHTS.	EQUAL VOLUMES.
Air.....	0.237	
Oxygen.....	0.218	0.240
Nitrogen.....	0.244	0.237
Hydrogen.....	3.409	0.236
Chlorine.....	0.121	0.296
Bromine.....	0.055	0.304

We have already arrived at the conclusion that, for equal weights, hydrogen would be found to possess sixteen times the amount of heat possessed by oxygen, and fourteen times that of nitrogen, because the hydrogen contains sixteen times the number of atoms, in one case, and fourteen times the number in the other. We here find this conclusion verified experimentally. Equal volumes, moreover, of all these gases contain the same number of atoms, and hence we should infer that the specific heats of equal volumes ought to be equal. They are nearly so for oxygen, nitrogen and hydrogen; but chlorine and bromine differ considerably from the other elementary gases.

Table XXIV on the next page shows the specific heat of the elementary substances in table II, together with their atomic weights and products, the gases in table XXIII excepted:

TABLE XXIV.

NAME.	SYMBOL.	SPECIFIC HEAT.	ATOMIC WEIGHT.	PRODUCTS.
Aluminum.....	Al	0.2143	27.5	5.89
Calcium.....	Ca	0.1670	40	6.68
Carbon (charcoal).....	C	0.2415	12.	2.90
Iron	Fe	0.1138	56	6.37
Magnesium.....	Mg	0.2499	24	6.00
Phosphorus.....	P	0.1887	31	5.85
Potassium.....	K	0.1696	39	6.61
Silicon (crystalized).....	Si	0.1774	28	4.97
Sulphur.....	S	0.1776	32	5.68

It will be observed, in examining the column of products formed by multiplying the specific heat and the atomic weights together, that there is a very close approximation to a constant product. Neglecting carbon and silicon, which are, apparently, exceptions—and this may in part be accounted for, as they are so diverse in their known or ordinary physical conditions, they have not, in general, the uniform type of conditions which are so characteristic of most of the other elements—aside from these, we find the lowest in this table to be 5.68, and the highest 6.61, making an average of 6.07.

If we were to obtain an average of all the products so far as known, it will be found to closely approximate 6.34. This is too close to be accidental, and the usual explanation is (3), that the atoms of the different ele-

ments have the same capacity for heat, and hence, that masses of the elementary substances containing the same number of atoms, must have the same capacity for heat when under similar physical conditions; the constant product being the amount of heat required to raise the temperature of such masses to the same degree.

SPECIFIC HEAT—The specific heat of a substance means the quantity of heat, expressed in thermal units, which must be transferred to or from a unit of weight (such as a pound) of a given substance, in order to raise or lower its temperature, by one degree, at a certain specific temperature.

According to the definition of a thermal unit, the specific heat of liquid water, at and near its temperature of maximum density, is *unity*; and the specific heat of any other substance, or of water at any other part of the scale of temperatures, is the *ratio of the weight of water at or near 39.1° Fahr., which has its temperature altered one degree by the transfer of a given quantity of heat, to the weight of the other substance under consideration, which has its temperature altered one degree by the transfer of an equal quantity of heat* (22).

The specific heat of a substance is sometimes called its “*capacity for heat*.”

The specific heats of water in the solid, liquid and gaseous state, are as follows:

Ice	0.504
Water	1.000
Gaseous steam.....	0.622

showing that, in the solid state, as ice, the specific heat of water is only half that of liquid water; and that, in the gaseous state, it is little more than that of ice, or nearly five-eighths that of liquid water.

TABLE XXV.
SPECIFIC HEAT OF FUELS. (AFTER REGNAULT.)

FUEL.	WATER AT 32°=1.
Oak wood.....	.570
Wood charcoal .....	.2415
Coal and coke, average (Rankine).....	.200
Coke of cannel coal.....	.20307
Anthracite coal, Welsh.....	.20172
Anthracite coal, American .....	.201

For all ordinary calculations it is a near enough approximation to assume that

Woods average one-half the specific heat of water.

Coal and coke, two-tenths the specific heat of water.

Wood charcoal, one-fourth the specific heat of water.

NOTE—Slight fractional differences will doubtless be observed in the specific heats of the same substances. These have been calculated by different observers widely separated, and are really marvels of accuracy, notwithstanding the differences, which are so slight as to cause no material error in any calculation. B.

TABLE XXVI.

SHOWING THE SPECIFIC HEAT OF GASES—WATER AT 32° FAHR=1.

GAS.	SPECIFIC HEAT FOR EQUAL WEIGHTS.		SPECIFIC HEAT FOR EQUAL VOLUMES.	
	AT CONSTANT PRESSURE.	AT CONSTANT VOLUME. (REAL SPECIFIC HEAT.)	AT CONSTANT PRESSURE.	AT CONSTANT VOLUME.
	WATER=1	WATER=1	AIR=.2377 AS IN COL. 2	AIR=.1688 AS IN COL. 3
Carbonic acid.....	0.2164	0.1714	0.3308	0.2620
Oxygen.....	0.2182	0.1559	0.2412	0.1723
Air.....	0.2377	0.1688	0.2377	0.1688
Nitrogen.....	0.2440	0.1740	0.2370	0.1690
Carbonic oxide.....	0.2479	0.1768	0.2399	0.1711
Olefiant gas.....	0.3694	0.2992	0.3572	0.2893
Hydrogen.....	3.4046	2.4096	0.2356	0.1667
Vapor of alcohol.....	0.4513	0.4124	0.7171	0.6553
Gaseous steam.....	0.4750	0.3643	0.2950	0.2262
Light carbureted hydrogen.	0.5929	0.4683	0.3277	0.2588

LATENT HEAT—Is that quantity of heat which disappears, or becomes concealed in a body while producing some change in it other than a rise in temperature. By exactly reversing that change, the quantity of heat which had disappeared is re-produced.

If heat is applied to a block of ice, having a temperature, say, ten or fifteen degrees below the freezing point of water, the temperature will continue to rise with each increment of heat until 32° Fahr. is reached, when the melting of the ice will begin; it will be observed that

the heat being transmitted to the ice, as before, there is no corresponding rise in temperature, either in the ice or the water in contact with it, so long as any ice remains unmelted; and, that during the process of melting the temperature of the water is constant, and at 32° Fahr.

Latent Heat of Fusion—This change of state from solid to liquid, in the melting of ice, requires one hundred and forty-three units of heat, the temperature being 32° as at first; the heat in this case does not raise the temperature of the ice, but disappears in causing its condition to change from the solid to the liquid state. According to our present theory (30), the heat expended in melting is consumed in conferring potential energy upon the atoms. It is, virtually, the lifting of a weight. The act of liquefaction consists of interior work—of work expended in moving the atoms into new positions. This is called the latent heat of fusion.

Latent Heat of Evaporation—After the ice, in the above experiment, has entirely disappeared, the application of heat being continued, the thermometer will begin, and will continue to rise until 212° Fahr. is reached, when it again becomes stationary, and will remain so as long as evaporation is continued at atmospheric pressure.

Again, it will be observed that heat disappears in the change of the water from the liquid to the gaseous state. Experimentally this has been ascertained to be nine hundred and sixty-six units of heat. From the

freezing to the boiling point there are $212 - 32 = 180^\circ$; so we find that $966 \div 180 = 5.37$ times as much heat is required to convert water into steam, at atmospheric pressure, as it requires to raise the temperature from the freezing to the boiling point. In the preceding section, the theory was given that the heat expended in melting the ice was consumed in conferring potential energy upon the atoms. In regard to the steam, or the evaporation of the water, the heat is consumed in pulling the liquid molecules asunder, conferring upon them still greater potential energy.

When the heat is withdrawn, the vapor condenses, the molecules clash with a dynamic energy, equal to that which was employed to separate them, and the precise quantity of heat then consumed re-appears (30). The act of vaporization is, for the most part, interior work; to which, however, must be added the exterior work of forcing back the atmosphere, when the liquid becomes vapor.

MECHANICAL THEORY OF HEAT—Professor Rankine's statement of the first law of thermodynamics is that,

"Heat and mechanical energy are mutually convertible; and heat requires for its production, and produces by its disappearance, mechanical energy in the proportion of 772 foot-pounds for each British unit of heat: the said unit being the amount of heat required to raise the temperature of one pound of liquid water by one degree Fahrenheit, near the temperature of the maximum density of water" (22).

This is also known as the dynamical theory of heat. The 772 foot-pounds as the mechanical equivalent of a heat unit, is often referred to as Joule's equivalent, and is so called in honor of Dr. Joule, of Manchester, England, who was the first to demonstrate experimentally the exact mechanical equivalent of heat. This honor Dr. Joule shares with Dr. Mayer, a physician in Heilbronn, Germany. The relations of these two men to the mechanical theory of heat is thus expressed by Professor Tyndall:

“The immortal investigations, here briefly referred to, place Dr. Joule in the foremost rank of physical philosophers. Mayer's labors have, in some measure, the stamp of a profound intuition, which rose, however, to the energy of undoubting conviction in the author's mind. Joule's labors, on the contrary, are an experimental demonstration. Mayer *thought* his theory out, and rose to its grandest applications; Joule *worked* his theory out, and gave it forever the solidity of demonstrated truth. True to the speculative instinct of his country, Mayer drew large and weighty conclusions from slender premises; while the Englishman aimed, above all things, at the firm establishment of facts. The future historian of science will not, I think, place these men in antagonism. To each belongs a reputation which will not quickly fade, for the share he has
ad, not only in establishing the dynamical theory of heat, but also in leading the way toward a right appreciation of the general energies of the universe.”

The apparatus employed by Dr. Joule, in the determination of this important constant, is represented in figure 7. A known weight was connected by means of cords to a shaft f , mounted on "friction-wheels," not shown in the cut; on this shaft a pulley was secured, and through the medium of another cord imparted motion to the shaft r , and caused it to revolve; at the lower end of this shaft r , were fitted eight sets of paddles, which, when connected by means of a pin P ,

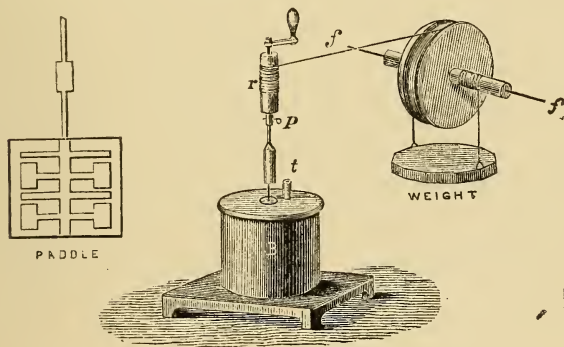


FIGURE 7.

revolved with it. To the interior of the copper vessel B were attached four stationary vanes, cut out in such manner as to permit the free revolution of the revolving paddles. Precautions were taken to prevent a transfer of heat from the vessel B , which need not be described here. This vessel was filled with a known weight of water, at the temperature of its greatest density (39° Fahr.), and a thermometer t , was inserted in the vessel B , to mark the rise in the temperature of the water.

The experiment consisted in allowing the weight to descend by its own gravity, and through the medium of the cords to cause the paddles to revolve and agitate the water in the vessel *B*.

Acting on the assumption that wherever there is motion there must be an evolution of heat, it was expected that, a weight falling through a certain distance must occasion a certain rise in temperature in a certain weight of water, this was found to be true; and after many hundreds of experiments, extending through several years, it was finally fixed by Dr. Joule at 772 pounds raised one foot high against the action of gravity, as the mechanical equivalent of the quantity of heat necessary to raise the temperature of one pound of water through one degree at its temperature of maximum density, or, from 39 to 40 Fahrenheit.

The following are the values of Joule's equivalent for different thermometric scales, and in French and British units:

One British thermal unit, or one degree Fahrenheit in one pound of water = 772 foot-pounds.

One French thermal unit, or one degree Centigrade in one kilogramme of water = 423.55 (say 424) kilogrammetres.

One degree Centigrade in one pound of water = 1389.6, or very nearly 1390 foot-pounds.

One *calorie*, or French thermal unit = 3.968 British heat units.

One British heat unit = .252 *calorie*.

UNIT OF HEAT—This is a conventional term expressing the quantity of heat required to raise the temperature of *one gram* of water from 4° to 5° Centigrade.

This is the French unit, and that principally used by chemists and scientific writers; it is sometimes spoken of as a *calorie*.

The unit in more general use among English and American engineers is the quantity of heat required to raise the temperature of *one pound* of water from 39° to 40° Fahr. This is the unit selected for use in this book.

A *thermal unit* and a *unit of heat* mean the same thing. The use of the word *calorie* should never be considered a synonym for, and should not be used to express an English unit, but should be referred to only as the French unit.

Many writers, inadvertantly perhaps, give the unit of heat as that necessary to raise one *gram* of water from 0° to 1° Cent., or one pound from 32° to 33° Fahr. This is an error; it is the raising of the temperature of water through one degree at its temperature of greatest density: this on the Centigrade thermometer is $3^{\circ}.94$, or 39.1° Fahr.

It will be near enough, however, for all practical purposes, to call the temperature of greatest density of water 4° Cent., or 39° Fahr.

CHAPTER XI.

THE CONSTRUCTION OF FURNACES.

Construction Depends on the Fuel—Conditions Attached to a Good Furnace—Why Ordinary Furnaces are so Wasteful—Volatilization of Gases in the Furnace—Quantity of Air Required—Force Blast—Description of a Reverberatory Furnace—Its Advantages—Increase of Efficiency by the Use of Hot Air—Loss by Chimney Draft.

This chapter is made up of selections from a paper read before the “Edinburgh and Lieth’s Engineers’ Society,” by Mr. Charles Fairbairn, a prominent manufacturer of iron, who has given this subject a great deal of personal attention.

His views are based upon correct theory, and confirmed by actual trial.

It is probable that much the same method of economizing fuel, as that suggested by Mr. Fairbairn, will sooner or later be largely employed in steam boiler furnaces; by this, is meant, the generating of an intense heat, and in large quantities, in a separate chamber, instead of directly under the boiler. The coal will probably be fed from underneath the fire; that is, the blast will pass through the fresh charge of coal in some manner analogous to that shown in the engraving of Mr. Fairbairn’s furnace; with any such arrangement as this, a force draft becomes a necessity; and by the use of a heated blast, instead of a cold one, a much higher

degree of economy may be reached than is possible by ordinary firing, and natural draft.

“The great variety of kinds of fuel, although they contain nearly the same ingredients, but in different proportions, renders it a somewhat difficult task to define what a furnace should be. Hydrocarbons, such as pitch, tar, naphtha and petroleum, have all to pass into the gaseous state before they can be burned.

“Coke, which is coal, with all the bituminous and gaseous portions taken out of it, is nearly pure carbon, with a small proportion of ash.

“Anthracite coal, which is very similar in its nature to coke, is wholly composed of free carbon. It is liable to split and fall into powder;* it burns without flame, and very little smoke, and requires a very strong draught.

“Bituminous coal, again, of which there is an immense variety, has a smaller proportion of carbon, with a mixture of hydrogen and oxygen. From this it will appear evident that special provision must be made for a supply of air to support combustion instead of the different kinds of fuel used. Thus, a furnace arranged for burning bituminous coal might be very wasteful in burning anthracite coal; due regard then must be paid in all cases to the character of the fuel employed.

The indispensable conditions attached to a good furnace, for all kinds of fuel, are,

1. A good draft, which can be regulated at will, so as to avoid forcing the fire too much.

* This remark does not apply to American anthracites. B.

2. A large and roomy combustion chamber, surrounded by fire bricks, and removed, if possible, from the place where the heat is to be used.

3. That the sides, or walls of a furnace, have at least ten thicknesses of bricks nearest the fire, and an outer wall having an air space between of about three inches.

4. That the supply of air to the furnace can be regulated at will.

“I do not think we can always command these conditions, especially in a furnace constructed on the principle of depending on atmospheric pressure for draught; and the reason is obvious, because in order to obtain a good and equal draught we require not only a tall chimney, but the chimney must be maintained at a high temperature, about six hundred degrees; and as the temperature within the furnace may be assumed at twenty-five hundred degrees, the abstraction of this large quantity of heat to keep the chimney at a sufficiently high temperature, amounts to one-fourth of the heat, and consequently of the fuel which is expended for that purpose alone. Nor is this the only drawback. The attendant on the furnace, who may, and often has other duties to perform, puts on a heavy load of coal. The flues and chimney are rapidly cooled, and the power of the draught reduced at the very time when it should be greatest.

“The second and third conditions mentioned may assist in getting over irregularity in the power of the draught to a certain extent—that is, a large and roomy

combustion chamber, and the sides constructed to prevent loss of heat.

“I do not suppose any person who has not had an opportunity of seeing a furnace in operation, with the heat confined in the manner described, could have believed the effect would be so powerful; the inner lining actually acquires a white heat, thus serving as an accumulator, which is given out again when the temperature of the fire is reduced (as in the case of a fresh charge of fuel), and at the same time assisting to bring the fresh fuel into active combustion more rapidly; the heat is again returned to the fire bricks, and kept ready for future use. Dr. Siemens has taken advantage of this idea, although in quite a different way, in his celebrated gas furnace.

“We will now consider our furnaces as at present constructed, and why they are so wasteful. We hear a great deal about thin fires and regular charges in the ordinary; and this is quite correct, inasmuch as it is the only way by which a right supply of air can be introduced to mix with and consume the gases. There are always two dangers we have to avoid: One is too much air, which is the least of the evils, and in which case a very large body of air passes away unconsumed, but it also carries away with it a certain amount of heat which cools the furnace and impedes the draught. The other evil of too little air is still more injurious, for the gases having only a small share of the oxygen required are burned into carbonic oxide, and this very often accounts for the deficient supply of steam from a boiler, in con-

sideration of the coal burned. But these fires are liable to burn into holes and admit streams of cold air; nor is this the only objection, for when the fire is fed with fresh coal, which must of necessity be very often, the new coal absorbs a large proportion of the heat of a thin fire, and immediately lowers the temperature.

“The fire contains a certain number of units of heat. If twice the quantity of coal was in active combustion, there would be double the number of units of heat, and it could therefore more easily sustain the reduction of temperature following a fresh charge of coal. I imagine the distillation of gas from coal or volatilization is a process similar to steam carrying off the heat from boiling water. The coal at first becomes an absorbant of the heat and then liberates the gases, and the volatilization of the bituminous portion of the coal acts in a similar manner to the production of steam, as I have said. The process is one of the most energetic known in cooling, because there is so large a portion of the heat converted from the sensible to the latent state.

“Regarding the quantity of air required in an ordinary furnace for the combustion of coal, I suppose very few people have any idea of the magnitude of the demand.

“It is generally given as 300 cubic feet, or 24 pounds of air to one pound of coal. Let us place this in another light:

“In my own establishment at Gateshead I have seven furnaces, each of which uses about one ton of fuel per day, in all about seven tons; therefore $7 \times 24 = 168$ tons

of air required. Again, a pound of coal requires about 300 cubic feet of air. If we imagine the 168 tons of air made into a long stream of one square foot in area, the total length will be 21,381 miles in length. Another great cause of the loss of heat, as before stated, is the quantity of heat continually passing away to the chimney.

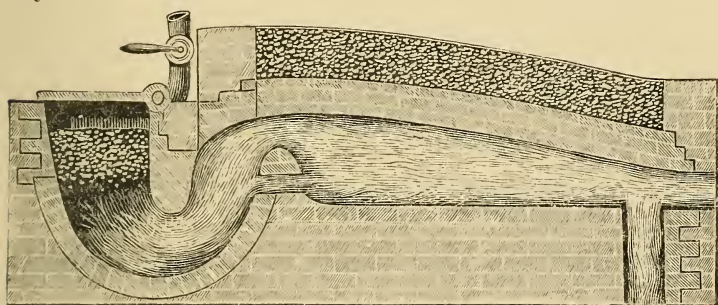


FIGURE 8.

“One difficulty—that is, regulating the supply of air to the furnace—can only be overcome by artificial means, either by a fan-blast or steam-jet. I believe the time is fast approaching when the supply of air to furnaces will be regulated in this way, as the most efficient and economical, and as obviating a great many of the faults of our present furnace.

“The idea is old enough. However, the arrangement of the furnace, I will describe presently, may or may not be new. I never saw it before, nor am I aware that anything of the same kind has been tried, and to it I have added a supply of air by means of a blower. In this furnace, of which the drawing is a longitudinal

section, the coal is introduced from the top, and is always on top of the incandescent fuel, at the side of the furnace furthest from the place where the flame makes its escape.

“The hearth is of fire-brick, and during the meal hours all the ashes and clinkers are removed by the hole in the side of the furnace.

“The blast is introduced above the new coals, and passes through them. As the coals begin to ignite, all the inflammable gases are forced through the fire, and at the same time mixed with air.

“The advantages with this kind of furnaces seem to be the following:

1. The whole of the gaseous products are made available.

2. There is entire absence of smoke, in consequence of perfect combustion.

3. There is a smaller quantity of air required, probably about one-fourth less; that is, about eighteen pounds of air to one pound of coal.

4. No increase of temperature above the external air is required in the chimney, and the escaping heat from the furnace can be used for other purposes.

5. A higher temperature in the furnace, and more rapid circulation of heat.

6. The perfect control which the attendant has over the furnace as regards temperature, getting the fire lighted and into operation in less time, when they have not been in use.

“There is also another very important point in connection with this method of making re-heating furnaces—that the air can be so nicely adjusted by means of the blast and damper, as to insure that nearly all the oxygen will be taken up by the carbon and gases, in consequence of which the iron is heated with scarcely any loss from oxide or scale.* The balance of pressure can be made so that even where there are unprotected inlets to the interior of the furnace, the flame can be made to come to the edge of the open space. I believe the efficiency of the furnace might be largely increased by using hot air, which might be done by passing it through pipes or brick work placed in the flues; for if we have the heat of the furnace twenty-five hundred degrees, and the entering air heated to five hundred degrees, the result would necessarily be a great saving. On this point we have the experiences of blast furnaces as an indication of what might be saved by this means alone.

I have again to mention that a furnace, which will suit admirably for one kind of coal, will not answer for another. Thus, the conditions under which coke and anthracite coal enter into combination with oxygen, are much less complex than in burning bituminous coal, and the great point to be observed is, that a large quantity be kept on the bars; there is not so much danger of the carbon passing away without its supply of oxygen—in fact it can not do so, as it can not rise until

*The reader will of course understand that the engraving is a section of, and the heating of the iron refers to a puddling furnace. B.

it has its quantity of oxygen to liberate it. In bituminous coal the bituminous portion is only serviceable for heat when converted into gas, while the carbonaceous portions are consumed only in the solid state, and they must be separated, as explained, before they can be consumed. Thus, when coke or anthracite coal are burned, the products are carbonic acid gas, and nitrogen; while with bituminous coal we have carbureted hydrogen, nitrogen and carbonic acid gas, or oxide.

“It is supposed that in some instances we have realized about seventy per cent. of the theoretical heat in fuel. This, I would be inclined to doubt. We have seen that with the ordinary furnace we lose about twenty-five per cent. in getting a draught; we have to add to this loss from small coal, too much or too little air; the products of combustion flying off to the chimney at a speed of thirty feet in a second in some instances, it must be abundantly clear that fifty per cent. of the heat of fuel we use is lost. It has been stated that, in some processes in connection with the manufacture of iron, the quantity of fuel used was sufficient to produce the desired result fourteen times if properly applied. I think it is clear we begin by placing the chimney at the wrong end of the furnace, and the air ought to be driven in, not drawn through. We have seen when a blast is used we can have a pressure in the furnace sufficient to balance the pressure of the atmosphere. The waste heat could also be made to do work in passing away. I dare say most of us now present can recall instances to our mind

where a number of furnaces are used, and where the heat of one, if it could be retained and applied, would be amply sufficient.

“The blast, then, is the only means of doing it, and I do not think the time is far distant when the hideous pillars we seem so fond of now will be no longer seen.”

CHAPTER XII.

MECHANICAL FIRING.

Objections to Hand Firing—Continuous Firing—The Requirements of a Self-feeding Mechanism—Description of M. Holroyd Smith's Furnace-Feeder.

There are several objections to hand-firing, when taken in connection with steam boiler furnaces. In order to get the best results from such a furnace the firing should be as nearly constant as possible, in order that chemical action may go on undisturbed. Hand firing must, from its nature, be intermittent, and therefore irregular. When the fire is brisk, and a boiler steaming rapidly, the opening of the furnace doors in order to admit a fresh charge of fuel, and thus allowing a draft of cold air, often below the freezing point of water, to impinge against the heated plates of the boiler, at the same time lowering the temperature of the gases in the furnace, and added to this, the deadening of a brisk fire by a fresh charge of coal, always in excess of actual requirements, and too often unevenly spread, is certainly not conducive to the highest economy.

The advantages of continuous firing were pointed out early in the present century, and a great number of devices have been tried from time to time, many of which have long since disappeared to give place to better contrivances to this end.

The ideal mechanism for feeding steam boiler furnaces, must, in addition to supplying the fuel, distribute it in such manner that it may be economically burned; it must admit a proper supply of air at the right time and place to insure perfect combustion, and prevent smoke; it should be adapted to the use of fine or slack coal, and preferably, granular fuel; it should be so arranged as to admit of a forced draft being used; it should admit the examination of the fire at all times, and the stirring or slicing of it whenever needed; it must permit the ready removal of clinker from the grate bars as fast as it accumulates; it must permit the ready removal of ashes from the fire, while in actual operation, without breaking it up, or destroying its efficiency; the parts should be few and free from complications; all moving mechanism should be protected from the heat and action of the fire; it should consist of parts easily made and repaired; and, as a whole, must combine utility, simplicity, economy, ease of management and durability.

The furnace-feeder, described below, was devised by Mr. M. Holroyd Smith, of England, and appears to combine most of the requirements enumerated above; and, in addition, it will be observed that the coal is forced into the fire from underneath, so that the volatile gases are extracted by the incandescent fuel above it, and burnt as fast as evolved from the fresh supplies. There are many other forms of furnace-feeders in use, and doing good service.

M. HOLROYD SMITH'S FURNACE FEEDER.*

"This invention relates to improved apparatus for supplying the fuel by self-acting mechanism, designed to supply the fuel from underneath the fire, the object being to insure more complete combustion, and, as a consequence, increased economy of fuel.

"This invention relates to an improved apparatus for feeding fuel to the grate of a furnace; and consists in combining the grate-bars of the furnace with troughs or screw-cases, that are placed between and communicate with the grate-bars, and are connected at one end to a feed-trough and a hopper, said screw-cases containing each a screw or worm, all being so arranged that the fuel is fed by the screws or worms from the hopper and feed-trough into the screw-cases, and from the screw-cases directly upon the grate-bars, all as is hereinafter more fully described. The screw has, by preference, two threads of such pitch and construction as to exert an outward and a propelling force. The propelling force of the screw at its commencement is in excess of its lifting force; but at its smaller end the lifting force is greatest, thereby insuring a uniform feed the whole length of the bars.

"I prefer to use my improved feed mechanism in connection with improved supplementary or auxiliary back grids or grates (placed off the ends of the furnace-bars) and apparatus for operating the same, so as to remove the spent fuel or ashes therefrom.

*Patented January 8, 1878.

"The auxiliary bars I mount on axles within a frame, and the bars are connected by a link-motion that, by working a "draw" or "push" rod, the bars will tilt and throw off the ashes or spent fuel delivered on them from the main fire-bars.

"The several parts will be clearly understood by reference to the drawings, aided by the description annexed.

"Figure 1 is a longitudinal elevation, partly in section, illustrating my invention applied to an internally-fired single-flue steam-boiler. Figure 2 is a plan of the same. Figure 3 is an elevation in cross-section, on line *a b* of figure 2, of some of the parts of the apparatus. Figure 4 is a front or outside elevation. Figure 5 is a plan view, enlarged scale, showing more clearly the screws and screw-case, the latter in section.

"Similar letters of reference indicate corresponding parts in all the figures.

"*A A A* are taper screws or worms; *B B B*, the screw-cases, connected at the front of the boiler by the feed-trough *C*, the latter being supplied with fuel by way of the hopper *E*. The screws *A A A* are supported at one end by the feed-trough *C*, and by contact with the bottom of the screw-case.

"Motion is given to the screws *A A A* by means of the ratchet-wheels *F F F* and pawls, linked together by bar *G*, and actuated by lever *H*; or the three worms *A A A* may be driven by longitudinal shaft-worm and worm-wheels.

“*J* is a frame, within which the auxiliary bars *K* are received, being free to tilt on their axles or gudgeons *L* when, by means of the rod *M*, the links *N R R* are operated, so as to tilt and thereby discharge the ashes or spent fuel from the bars to the bottom of the flue.

“Two screws may be put in one screw-case.

“I do not claim as my invention the use of a screw *per se*; but

“I claim—

“The combination of the grate-bars of a furnace with the troughs or tapering screw-cases *B B*, that are placed below and between, and communicate with the several grate-bars, and connect at one end to a hopper, each of said screw-cases containing a tapering screw or worm, *A*, so arranged that the fuel is fed by the screws or worms *A* from the hopper into the screw-cases *B*, and from the screw-cases directly upon the grate-bars, all substantially as and for the purpose herein shown and described.”

M. H. SMITH. FURNACE FEEDER.

FIG. 1.

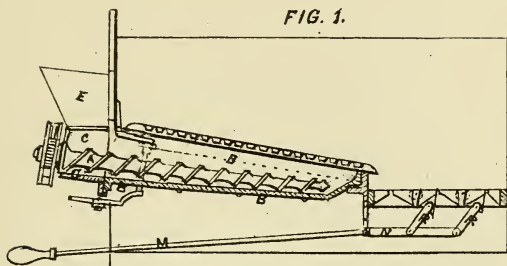


FIG. 2.

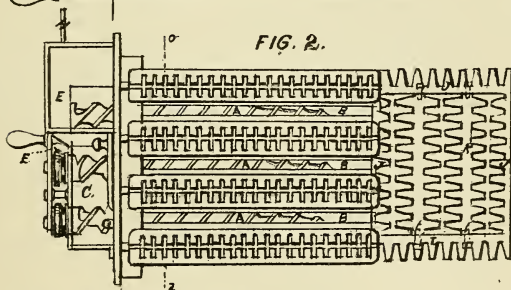


FIG. 5.

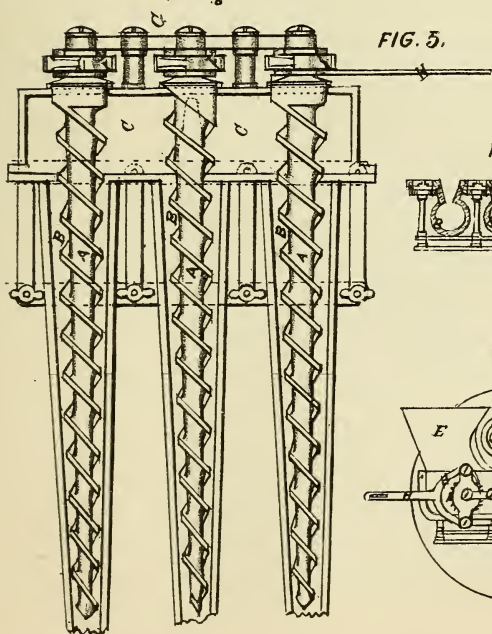
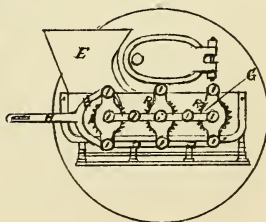


FIG. 3.



FIG. 4.



CHAPTER XIII.

SPONTANEOUS COMBUSTION OF COAL.*

Most Likely to Occur on Board Ships—Vessels Lost from this Cause in 1874—Spontaneous Combustion Begins in the Center of the Heap or Middle of the Cargo—Iron Pyrites in Coal—How Carbon Spontaneously Ignites—Coal requires no Initial Temperature for its Combustion—No Limit to the Heat which may be Produced by Concentration.

“The most serious cases of spontaneous combustion are in ships carrying coal. These have of late been so numerous, and have so often occurred in despite of manifold precautions, that a royal commission was recently appointed to make inquiry into the causes of these terrible catastrophes, and to suggest remedies which it may be possible to adopt for preventing and guarding against them. Numerous board of trade inquiries had already been made into casualties caused by explosions or fires in coal-laden vessels, but without any improvement in the safety of shipment resulting therefrom, until, at length, the board declined to hold any more, for the reason that the findings of their courts (which invariably took the form of an exoneration of the ship’s officers, and a recommendation in favor of better ventilation) appeared to be entirely disregarded, both by shipping and underwriting interests.

“It was evident, from this state of things, that the coal shippers conceived that they knew more of the

* Charles W. Vincent, F. R. S. E., F. C. S.

causes of these accidents than did the assessors of the board of trade. The Salvage Association thereupon urged that an inquiry should be held by a commission, consisting of men of high scientific attainments, and especially acquainted with the nature of coal in all its conditions, and of men practically acquainted with coal, both at the pit and in the ship's hold. They pointed out that the result might be to fix, with a certainty absolute or qualified, the causes of this dangerous combustion, thereby attaching to proper persons the responsibility for due precautions.

“The commission sat, and has now issued its report, from which much valuable information as to the nature of these disasters can be obtained, and, to a certain extent, modes of preventing them, though this part of the subject still requires most serious consideration, since at present the carriage of coal for a long distance at sea must be regarded as hazardous, whatever precautions may be adopted.

“At the commencement of the inquiry, they were struck by the circumstances that by far the greater part of the casualties happened on board ships which were on long voyages. In 1874, among thirty-one thousand, one hundred and sixteen shipments, amounting to upwards of thirteen million tons of coal, the accidents were seventy. But of these shipments, twenty-six thousand, amounting to over ten million tons, were to European ports. This left sixty casualties among only four thousand, four hundred and eighty-five shipments, amounting to two million, eight hundred and fifty-five

thousand, eight hundred and thirty-one tons of coal, to Asia, Africa and America.

“Again, they were startled to find that the proportion of casualties traceable to spontaneous combustion increases, *pari passu*, with the tonnage of the cargoes. This becomes still more apparent when the European trade is deducted.

“There were in 1874—

“Two thousand one hundred and nine shipments with cargoes under five hundred tons, in which five casualties occurred, or under one-fourth per cent.

“One thousand five hundred and one shipments, with cargoes between five hundred tons and one thousand tons, in which seventeen casualties occurred, or over one per cent.

“Four hundred and ninety shipments, with cargoes between one thousand and one thousand five hundred tons, in which seventeen casualties occurred, or three and a half per cent.

“Three hundred and eight shipments, with cargoes between one thousand five hundred and two thousand tons, in which fourteen casualties occurred, or over four and a half per cent.

“Seventy-seven shipments, with cargoes over two thousand tons, in which seven casualties occurred, or nine per cent.

“The casualties in vessels bound to San Francisco were the most remarkable. Deducting vessels under five hundred tons (in which no case of spontaneous

combustion were recorded) the returns show nine casualties out of fifty-four shipments. These also increase in proportion to the tonnage of the cargoes, till we find that, out of five ships with cargoes of over two thousand tons sent to San Francisco in 1872, two suffered.

“Careful thought might have predicted results of this kind from a consideration of the nature of the substance carried, the mode of carriage, and the place to which it was going.

“So long ago as 1852, Graham pointed out that the tendency of coals to spontaneous ignition is increased by a moderate heat, and gave examples. For instance, in one case coal had taken fire by being heaped for a length of time against a heated wall, the temperature of which could be easily borne by the hand; in another, coals ignited spontaneously after remaining for a few days upon stone flags covering a flue, of which the temperature never rose beyond 150° Fahr. Coals thrown over a steam-pipe ignited, etc. At the Chartered Gas Works, coals piled against a brick wall two feet thick, of which the temperature did not exceed 120° to 140° Fahr., became ignited. Neither did it appear to matter whether the coal was Lancashire and sulphurous, or Wallsend and bituminous. If they were exposed to this very moderate heat for a short time they were sure to ignite.

“Coals conveyed through the tropics are certainly in this state of danger. When coal takes fire spontaneously, it is invariably in the center of the heap of small coal at the foot of a hatchway, or in the middle of

the cargo, in this respect resembling the spontaneous combustion of hay-stacks, oily waste, etc., and from hence it may be inferred that the increments of heat which cumulate in vivid combustion are very small, since they require to be held prisoners by impassable barriers of non-conducting matter, or they would escape.

“Coal in small quantity, and in a cool place, never ignites spontaneously, but it does not, therefore, follow that all the conditions leading up to spontaneous combustion are absent, but only that one of them, and that an all-important one, the means of accumulating of heat, is absent, since the barriers interposed to its escape are not sufficiently close-fitting.

“The large ships to San Francisco had to encounter elevated temperature, and at the same time the coal was in great mass; they were, therefore, much more liable to accident than those carrying smaller quantities, and for shorter distances.

“It has already been pointed out that, whilst wood is living, moderate heat, so far from causing its destruction, promotes its growth; it is the heat which disappears, not the plant. When the wood has ceased to live, moderate heat dries up its juices, renders it brittle, and ultimately causes its complete disintegration, and combustion of air is supplied, though the process is exceedingly slow. Some years ago, the sawdust packing round a steam pipe at the Queen’s Printing-office, Shacklewell, was found to be charred. Wooden beams resting against hot plates which never reach the boiling point of water, are sometimes found to be charred, but

oxygen being of necessity excluded by the position of the wood, combustion does not happen.

“At the ordinary temperature of the air, oxygen has so little action upon wood that it is practically indestructible. In coal, however, the wood has undergone changes which render it far more readily affected by the oxygen of the air than it was heretofore, and it must be borne in mind that if once a combustion is sufficiently rapid to overcome the cooling effect of currents of air, it will proceed with increased vigor, and the ignited coal will burn, not only in the interior of the cargo or heap, but on its surface also. Knowing, then, that coal, if kept in bulk at a temperature slightly raised above the common is sure to ignite, the question still remains, how does it attain the degree of heat at which active combination can take place? And at what temperature do the combinations of the carbon and oxygen, the hydrocarbons and the oxygen, begin to take place? In other words, what is the temperature of the initial point of the combustion, and how is it reached? Many explanations have been given. The well-known fact that heaped-up iron pyrites in shale, when wetted, often causes the combustion of the pile, as in alum making, has been used as an argument against the shipment of “brassy” coal, *i. e.*, coal containing these pyrites. But supposing this were so, and that the pyrites were disseminated through a part of the cargo in sufficient quantity to cause evolution of heat when wetted, this would account for but a small number of the cases of

spontaneous combustion of coal, since by far the larger number happen with coal free from pyrites.

HOW CARBON SPONTANEOUSLY IGNITES.

“Condensation of oxygen, by carbon, which was referred to at the outset of this paper, is a far more likely mode of attaining the initial temperature. This is pointed out by Professor Abel and Professor Percy in the appendix to the report of the Royal Commission. As already stated, carbon, in a finely divided state, has the power of condensing oxygen within its pores; now, to condense a gas, force is consumed, and heat is produced. In the fire-syringe a piece of tinder is set on fire by the heat evolved by the condensation of the air. When charcoal condenses oxygen, heat is liberated, and if the charcoal is freshly burned, the rapidity of the action will produce such an amount of heat as to cause the chemical combination of the oxygen and carbon, when, of course, combustion takes place with evolution of light and heat. The initial temperature of the action is here due to the sudden squeezing together of the gaseous molecules, for if the air be admitted to the freshly burned charcoal by slow degrees, no combustion takes place.

“The appendix suggests:

“The tendency to oxidation, which carbon and carbon compounds, existing in such a substance as charcoal, possess, is favored by the condensation of oxygen within its pores, whereby the very intimate contact between the carbon and oxygen particles is promoted. Hence,

the development of heat, and the establishment of oxidation occur simultaneously, the latter is accelerated as the heat accumulates, and chemical action is thus promoted, and may, in course of time, proceed so energetically that the carbon or carbo-hydrogen particles may be heated to igniting point.

“‘This explanation has a direct bearing upon a spontaneous ignition of coal. The more porous and readily oxidizable portions of coal, which are known to be more or less largely disseminated through seams from different localities, undergo oxidation by absorption of atmospheric oxygen, and by the exposure of large surfaces to its action, and the heat developed by that action will accumulate, under favorable conditions, to such an extent as soon to hasten the oxidation and the consequent elevation of temperature, until some of the most finely divided and readily inflammable portions actually become ignited.’”

“Water does not assist in the spontaneous combustion of coal except where pyrites are concerned. There is much misunderstanding as to the part played by water in the changes leading to spontaneous combustion. The water itself is not decomposed, as some people have imagined. The heat evolved during the combustion of hydrogen and oxygen, during the combination to form water (the heat of the oxy-hydrogen blow-pipe) must be supplied before they can be again torn apart, so that, so far from water being a producer of heat, it is likely to be a consumer.

“Moreover, experiment goes to prove that coal requires no initial temperature for its combustion, and that the supposition of condensation by porous coal, though it may take place, is unnecessary for its spontaneous combustion. The ties holding the constituents of coal together, which in the living plant were so strong that they defied the power of the sun to rend them asunder, have now become so weak that the oxygen of the air, even when no hotter than fifty-five degrees Fahr., can seize upon and combine with at least some of the carbon, forming carbonic acid. Air blown through a tube filled with coarsely powdered coal, into baryta water, furnishes a considerable amount of barium carbonate in a very short time. Other circumstances may aid, but it is sufficient to prove the production of carbonic acid to make it certain that heat is set free, and if escape of the heat is barred, it must accumulate, till at length it reaches the point at which combustion becomes visible, and in too many cases uncontrollable.

“As there is no amount of cold which may not be intensified by free radiation, so there is no limit to the heat which may be produced by concentration, or, in other words, by stoppage of all radiation except to one common point. Siemens’ admirable regenerators act on the principle of continuous passage of heated gases through passages, where the gases are deprived of heat; when the heat producers go forth to do their work, they are first made to pass through these heated passages. In addition to their own proper heat, they thus

convey forward the stored-up heat, and the most intense heat yet met with for practical purposes is attained.

"It is to be feared that, in ventilating the cargoes of coal-ships, the principle of Siemens' regenerator is infringed upon, to the great damage of the cargo. Air is forced through the coal, oxidation and heat follow throughout its course, the heat is absorbed by the coal, and the air, as it is continuously forced in, passes over surfaces which are becoming hotter and hotter, the air is itself heated, and the work of combustion, once begun, goes on more and more rapidly.

"In view of these facts, there is small wonder that the uniform recommendation of the Board of Trade Assessors, 'to ventilate the cargoes,' should have met with cavalier treatment. The subject is, however, yet far from being fully understood. Evidence has been collected from most trustworthy sources, and a clear understanding obtained of the various conditions under which spontaneous combustion of coal takes place. What is now wanted is, a thorough experimental investigation of the causes of the spontaneous combustion. The reasons already given are probably correct, but they are supported by the feeblest experimental support, and until this is strengthened, we can neither speak with the necessary boldness in reproving the actions which lead to the lamentable losses of good fuel, good ships, and, but too often, of good men; nor can we decide as to the proper means for preventing their occurrence."

CHAPTER XIV.

COAL-DUST FUEL.

Continuous Firing—How a Furnace should be Fed when Using Powdered Fuel—Experiments of United States Government in 1876—Comparative Economy of Powdered Fuel as Compared with Ordinary Coal—Stevenson's Apparatus for Burning Coal-Dust.

COAL-DUST FUEL (8).

When coal is burned in large lumps a certain amount of power is expended in the furnace in disintegrating the fuel. This is, however, comparatively a small matter. But it is obvious that difficulties are thrown in the way of the union of the carbon with the oxygen of the air, and it has come to be recognized as a feature of good stoking that the coal should be broken into moderately small pieces before it is put into the furnace, and that the process of firing should be as continuous as possible. The great advantage derived from the use of mechanical stokers lies no doubt in the almost perfect fulfillment of the last named condition. If we carry the idea a little further, the use of coal in a state of powder will suggest itself; and as it is impossible to feed a fire satisfactorily by hand with coal-dust, it has come to be understood that it should be blown into the furnace with the air required for its combustion, which is thus intimately mingled with the carbon. Until a very recent period this system was only used by Mr. Crompton, whose well known revolving puddling

furnace is supplied with powdered coal by a fan blast, the coal being first ground very fine between an ordinary pair of millstones. We believe that at one time Mr. Crampton applied this system, but without success, to a steam boiler. We are not in possession of any of the details of this experiment, and so we can say nothing about the cause of failure.

UNITED STATES EXPERIMENTS.

In 1876 a series of trials were conducted by the American Government to determine the value of a system of burning powdered fuel, patented by Messrs. Whelpley and Storer.

The boiler was forty inches in diameter and ten feet long; it was a plain cylinder externally fired, the products of combustion returning to the front end through seventy-four tubes two and one-quarter inches in diameter outside; the total heating was four hundred and forty-two square feet. The air required for combustion was delivered into the closed ash-pit, vertically, through a pipe five inches in diameter. The powdered coal was sent in through a pipe two inches in diameter, arranged horizontally. The boiler was tried both with powdered anthracite and lump anthracite, the only change made as regards the boiler consisting in the removal of a brick arch used with the dust fuel. This increased the heating surface to four hundred and fifty-seven square feet. Each experiment lasted forty-eight hours. Four experiments were made; two with lump coal alone, and two with lump coal supplemented by dust coal below or above it.

“Results of Experiments—Calling the experiments with lump coal alone *A*, and those with dust coal *C* and *D*, the results may be briefly stated as follows: In experiment *A*, 11.113 pounds of lump coal were consumed per hour per square foot of grate surface, with 80.478 double strokes of the piston of the engine supplying air; the resulting vaporization per pound of the combustible portion of the coal was 10.124 pounds of water from the temperature of two hundred and twelve degrees Fahrenheit, and under the atmospheric pressure. The mean rate of combustion in experiments *C* and *D* was 11.350 pounds of the combustible portion of the coal consumed per hour per square foot of grate surface, with 79.748 double strokes per minute of the piston of the engine supplying air, the resulting vaporization per pound of the combustible portion of the coal being 10.192 pounds of water from the temperature of two hundred and twelve degrees Fahrenheit, and under the atmospheric pressure. The two economic results—namely, 10.124 and 10.192—are almost identical, and show, when semi-bituminous coal is burned at the same rate of combustion, with the same *pro rata* air admission, and under the same circumstances, it gives the same economic vaporization, whether it is consumed wholly in the lump state, or partly in the lump and partly in the pulverized state, or wholly in the pulverized state. The equality of economic result is also proved by the fact of the equality of the temperature of the gases of combustion in the comparable experiments when leaving the boiler.

In experiment *A*, burning lump coal alone, this temperature was 383.30 degrees Fahrenheit, while the mean of the temperature of the gases of combustion in the boiler-uptake during experiments *C* and *D*, during which partly lump coal and partly pulverized coal were consumed, was 381.85 degrees Fahrenheit. This comparison is made, however, for the heating effects alone of the coal in the two states, burned under the same circumstances, and is exclusive of the cost in fuel of pulverizing the coal, and of blowing the dust into the furnace. A correct commercial comparison must include this cost, which is only incurred when the coal is used in the pulverized state, because when it is used in the lump state it can be burned as rapidly with the natural draught as the pulverized coal can with the artificial draught obtained by the fan-blowers. The reason why the pulverized coal can not be consumed at a greater rate with the fan-blowers than the lump coal can be consumed with the average draught given by the boiler chimney is, that the former requires a certain time for ignition and combustion, which is much longer than the latter requires, because the temperature to which the former is exposed above the bed of incandescent fuel on the grate-bars is much less than the temperature of that bed to which the latter is exposed.

“The cost of the net horse-power in average practice may be taken at about four pounds of coal per hour. Now, the mean of experiments *C* and *D* gave 1.381 net horse-power developed by the engine in pulverizing the coal, and in blowing the dust into the furnace, and in

pumping the feed-water into the tank, which, at four pounds of coal per hour per horse-power, is 5.524 pounds of coal per hour, or, as the coal consumed per hour was 66 pounds, 8.37 per cent. of the total weight of coal burned. Consequently, the pulverized coal was commercially 8.37 per cent. inferior to the lump coal. In experiment *A*, during which lump coal was burned alone, there was required to drive the fan-blowers and to pump the feed-water 0.500 net horse power, which, at four pounds of coal per hour per horse-power, required 2.000 pounds of coal per hour to produce it, and as the hourly consumption of coal during that experiment was 66 pounds, there were consumed in producing the artificial draught and in pumping the feed-water 3.06 per cent. of the total weight of coal burned. Deducting this 3.06 per cent. from the 8.37 per cent., as given in the immediately preceding paragraph, there remains 5.31 per cent. of the total weight of coal consumed, applied to the pulverization of the coal alone.*

“From this it will be seen that the use of powdered fuel was more expensive than that of lump coal, about in the ratio of the cost of pulverization, and so far the scheme was a failure. As regards the details of the apparatus used our information is meagre. Mr. B. F. Isherwood, by whom the experiment was made, thus comments on it: ‘The lump coal is first reduced by a patented apparatus (which is the only portion of Messrs. Whelpley and Storer’s process that is patented or patent-

**Vide* Annual Report of the Chief of the United States Bureau of Steam Engineers for 1876.

able) to the state of impalpable powder, and it is then fed, together with air, through a conduit to the central portion of an ordinary centrifugal or fan-blower, whose revolutions draw it in and drive it through another conduit, which discharges it into the front of the furnace through an air-tight aperture. The lump coal is fired in the usual manner, through the furnace-door, and the air for its combustion is supplied by another fan-blower delivering into a closed ash-pit beneath the grate-bars. The whole combustion is, therefore, effected by artificial draught depending on mechanism; and the force of this draught is easily regulated from the least to the greatest desirable in burning coal; it can also be distributed at will, so as to preserve within certain limits any required proportion between the weights of lump and dust coal consumed in the same time. The two fan-blowers, in the experiments described, were operated by the same steam engine which effected the coal-crushing and worked the feed-pump of the boiler.

Why the Experiments were made—"The patentees imagine that, compared with the combustion of lump coal, a more nearly perfect combustion was to be obtained with impalpably fine coal-dust mixed thoroughly with and suspended in air, thereby presenting to the latter, for a given weight of coal, an immensely greater surface than in the lump state. They imagined, too, that, from the same cause, a much higher rate of combustion would be obtained than was probable with lump coal, by which means a boiler with a much smaller grate-surface, but with the same heating surface, would

furnish with the coal-dust the same quantity of steam in equal time, and with greater economy of evaporation per pound of fuel than with the lump coal. It was to determine the truth or error of these assumptions that the experiments were made. They were intended to have been very extensive, embracing anthracite and coke, as well as bituminous and semi-bituminous coals; and also a species of exceedingly hard anthracite, found in Rhode Island, which contains about forty per centum of incombustible mineral matter, and is worthless, from its difficulty of ignition and slowness of combustion, for burning in lumps. The results from different rates of combustion and different proportions of dust, to lump coal consumed in equal time, were likewise to have been ascertained, but the experiments were prematurely closed, as the government could no longer dispense with the services of the naval engineers making them.

“The obvious defects of the scheme were, that the coal could not be burned fast enough, and it is instructive to note that the cooling down of the furnace of the boiler was one principal factor in bringing about this result.”

STEVENSON'S APPARATUS.

Plate IV is a representation of the apparatus for burning coal-dust, the invention of Mr. G. K. Stevenson, of Valparaiso, and which has been at work in Wellington street, Blackfriars, London. This apparatus overcomes, it would appear, the objections urged against Messrs. Whelpley and Storer's plan, and deserves attention from engineers. The apparatus is

illustrated in the accompanying engravings, and may be briefly described as follows: The boiler used is one of two precisely alike, placed side by side, as shown. They are Cornish boilers, with a single flue in each, and are of the dimensions shown in the drawing. Confining our attention to that to which Mr. Stevenson's invention is affixed, it will be seen that the grate-bars are removed, and in the furnace is placed a species of fire-clay retort, the sides of which are perforated with numerous holes, about a half inch in diameter. The air and powdered fuel are driven in together through the pipe *B*, which is six inches in diameter. A few fire-bricks are arranged in the flue, behind the retort, to act as a bridge.

“The coal is reduced to a fine powder by a small disintegrator, which delivers into a closed sheet iron tank to prevent the escape of dust. It is brought to the condition of a somewhat coarse powder, and is not impalpable. The appliances in use in Wellington street are, in many respects, makeshift, and the powdered fuel is conveyed by hand to a hopper, *E*, figure 2. In the base of this hopper is a small delivery wheel, *C*, in the rim of which are notches *c c*. These notches are provided with slides worked by a very simple arrangement, which compels them to obey the action of gravity and fall to the bottom of the notches when they are at the top of the wheel *C*. The notches then fill with coal-dust, and, as the wheel revolves, the slides, being thrust downward, push the coal out of the notches into the air tunnel *B B*. The rate of delivery of the coal can

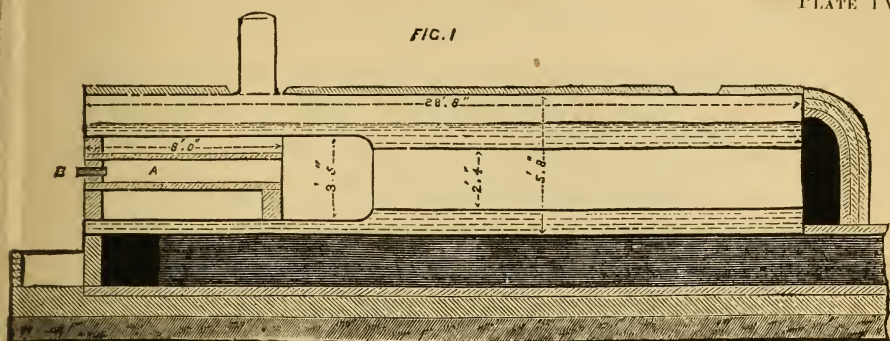
thus be accurately fixed by regulating the speed of the wheel *C*, which is driven by a face friction wheel, in a way that will be readily understood. By setting the friction wheel nearer or further from the axis of *C*, the speed of the latter can be altered without affecting that of any other portion of the apparatus. In order to mix the coal-dust with the air, a twisted plate of metal, *g g*, is put in the air tunnel. This causes a rotary motion in the current, and produces the required effect. *B B* is prolonged into the firing place, and coupled on to the pipe *B*, figure one, by a socket. The air is supplied by a blower *A A*, figure two, driven by a belt from a lay-shaft. The apparatus is started by lighting a fire in the retort *A*, figure one. After this has burned up, if steam be available, the blower is set in motion and coal-dust and air fed into the retort, the front of which is bricked up, as shown in the end view of the boiler, figure three.

"Several experiments have been carried out to test the value of the apparatus. One by Mr. T. B. Jordan, of Queen Victoria street, lasted five hours and fifty-five minutes. The boiler evaporated 5984 pounds of water from eighty-one degrees with 720 pounds of coal, or 8.312 pounds per pound of coal. In a previous experiment, lasting five hours, the same boiler, fired in the ordinary way, evaporated 10.194 pounds of water with 1568 pounds of coal, or at the rate of 6.501 pounds per pound of coal. In a third experiment, made by Mr. G. Barker, of Birmingham, the trial lasting five hours and fifty-five minutes, 720 pounds

of coal were burned, and evaporated 5984 pounds of water, or at the rate of 8.312 pounds per pound of coal from fuel at eighty-one degrees, the pressure being forty-two and one-half pounds. In an experiment with the same boiler, hand fired, the evaporation was 6.5 pounds per pound of coal.

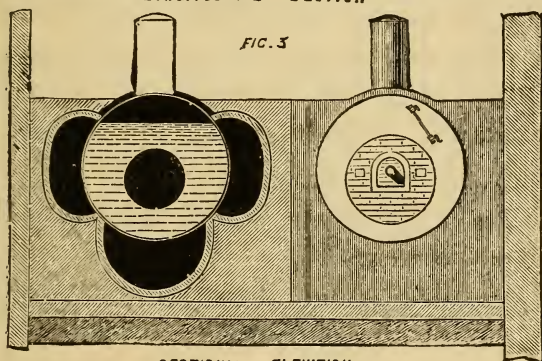
“More recently we carried out ourselves an experiment which lasted two hours. The boiler was filled up to begin with, and the experiment commenced when the pressure was 44 pounds. During the run no water was fed into the boiler. After it was over the donkey was started and the boiler pumped up to the same level as at starting. The stop-valve being closed, the pressure rose, notwithstanding the feed—a result due to the intense heat of the clay retort and fire-bricks. The whole quantity evaporated was thirty-five cubic feet, or twenty-one hundred and eighty-four pounds. The weight of coal burned was 176.5 pounds, and it follows that 12.3 pounds of water per pound of coal were evaporated from and at a temperature of two hundred and ninety-one degrees. It will be seen that the rate of evaporation was extremely low for so large a boiler, and it is proper to add that the blower, which ran at an average speed of two hundred and sixty revolutions per minute, was driven by a lay-shaft running too slowly, but over which Mr. Stevenson had no control. The speed also varied considerably, which was against the performance of the apparatus. Throughout everything worked perfectly without a hitch or difficulty of any

FIG. 1



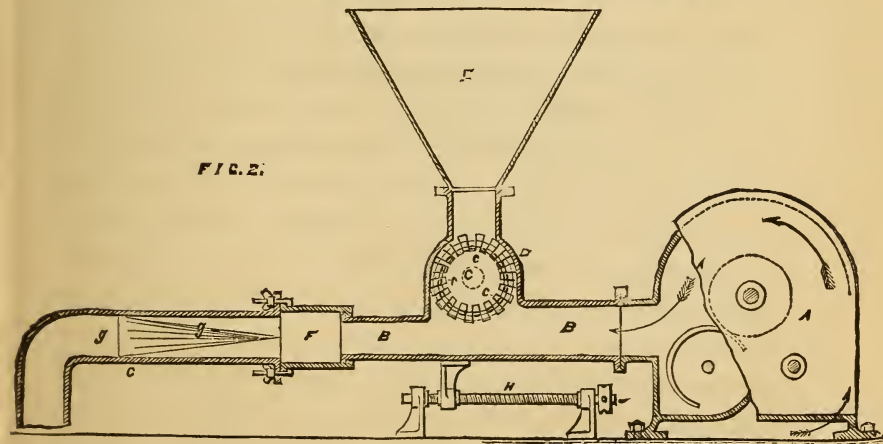
LONGITUDINAL SECTION

FIG. 3



SECTIONAL ELEVATION

FIG. 2:



STEVENSON'S APPARATUS FOR BURNING POWDERED FUEL.



kind; and the closing of the boiler front rendered the firing place exceedingly cool—a manifest advantage.

A curious feature of Mr. Stevenson's apparatus is, that the quantity of air admitted per pound of coal admits of accurate determination. During the trial, at which we were present, the blower supplied 1.2 cubic feet of air per revolution. This was determined by measuring the capacity of the blower, and checking the result with a delicate anemometer, placed at the mouth of the coal delivery pipe, the coal being shut off. Now $1.2 \times 260 = 312$ cubic feet, or twenty-four pounds of air per minute. The coal supplied in the same time was two pounds nearly. Thus only twelve pounds, or the least possible quantity of air which will suffice for combustion, were supplied. Yet there can be no doubt that no smoke was produced, nor does it appear possible that any coal-dust was deposited unconsumed in the flues.

We have endeavored to place our readers in possession of all the available information concerning a new and important branch of physical inquiry. It can be easily shown that in theory, at all events, the combustion of fuels in the form of dust ought to be attended with excellent results; and Mr. Stevenson proved that an apparatus can be made which will work without giving any trouble, and which is inexpensive and simple. But we have, on the other hand, no data concerning the cost of breaking the fuel, and the apparatus is quite too small, or at least is run too slowly, to enable any estimate of its value to be formed which can be

based on fact and not on conjecture. The retort used by Mr. Stevenson is far too small, and consequently does not fit the flue properly.

The retort must reduce the efficiency of the heating surface to some extent, as it is certainly not as hot as a furnace would be.

It appears to be proved by the facts which we have placed before our readers, that a retort, or its equivalent, can not be dispensed with, and it is shown that a chemical equivalent of air will suffice to produce combustion without smoke. This last is an important fact, and would, standing alone, entitle the invention of Mr. Stevenson to consideration.

CHAPTER XV.

LIQUID FUEL.

Analysis of Crude Petroleum—Quantity of Air Required to Burn Oil—Units of Heat Evolved by the Combustion of Oil—Evaporative Power of Crude Oil—What is Claimed for Petroleum as a Fuel—Wise, Field and Aydon's System of Burning Liquid Fuel—Extraordinary Results Obtained—Advantages Arising from its Use on board Steamships and Vessels of War.

Petroleum is a natural hydrocarbon oil. That of Pennsylvania, from whence most of the American petroleum is shipped, is of a dark brown color, having a greenish tinge. In specific gravity it averages about 0.8, though it varies some .025 on either side of this figure. As there is apparently no end to hydrocarbon combinations, the analysis of crude petroleum, as determined by Professor H. Wurtz, will be given as best suited to our present purpose, which is as follows:

Carbon	84
Hydrogen	14
Oxygen.....,	2
	<hr/>
	100

Deducting the oxygen and the quantity of hydrogen to form water, we have

$$2 \div 8 = .25 = \text{useless hydrogen.}$$

Then,

$$14 - .25 = 13.75 \text{ available hydrogen,}$$

and

$$2 + .25 = 2.25 \text{ water,}$$

or

Carbon	84
Hydrogen.....	13.75
Water	2.25
	<hr/>
	100

The net theoretical quantity of air required to burn the carbon to carbonic acid, and the hydrogen to water, in the above composition, would be,

$$.84 \times 12 = 10.08 \text{ pounds of air for the carbon.}$$

$$.1375 \times 95 = 4.36 \text{ pounds of air for the hydrogen.}$$

The total estimated quantity of heat that can be given off, by the complete combustion of the above, would be,

$$\text{Carbon.....} .84 \times 14,544 = 12,217$$

$$\text{Hydrogen.....} .1375 \times 62,032 = 8,529$$

$$20,746 \text{ units of heat.}$$

The theoretical evaporative power, or the number of pounds of water which may be evaporated at 212° , and at atmospheric pressure, by one pound of oil, as above, and containing twenty thousand seven hundred and forty-six heat units, the feed water being supplied the boiler at 80° Fahr., may be determined as follows:

$$212^{\circ} - 80^{\circ} = 132^{\circ} \text{ difference in temperature.}$$

$$966 \div 132 = 1098$$

Then,

$$\frac{20,746}{1,098} = 18.89 \text{ pounds of water.}$$

The total equivalent evaporative power of one pound of oil, as above, from and at a temperature of 212° Fahrenheit, and at atmospheric pressure is,

$$\frac{20,746}{966} = 21.47 \text{ pounds of water.}$$

In these several calculations the whole of the carbon, and the *excess* of hydrogen only, have been used. The whole of the oxygen and the combining weight of hydrogen to form water have been deducted from the total analysis. It is probable that the figures given above represent a fair average of the total heating power of crude oil. The writer is not aware that any calorimeter tests of crude American petroleum have been made.

It is claimed for petroleum that, on account of its superior heating power, a sensible reduction in the size of steam boilers may be made under that required for coal, or, the boiler remaining the same, more water may be evaporated, and thus its capacity increased. So little is known, however, of the actual economic efficiency of liquid fuel over coal, under all conditions, that the best form of furnace, and best design for the boiler, can hardly be said to have been practically determined.

It certainly has cleanliness in its favor, as there are no ashes or clinkers left in the furnace. It also permits of continuous firing in a closed furnace, free from drafts of cold air. The quantity of heat required to maintain a

constant pressure of steam may be controlled by the simple adjustment of a valve in the oil supply pipe. It is obvious that by this method of firing, one man may attend a number of furnaces, and thus dispense with firemen, coal heavers, and other attendants.

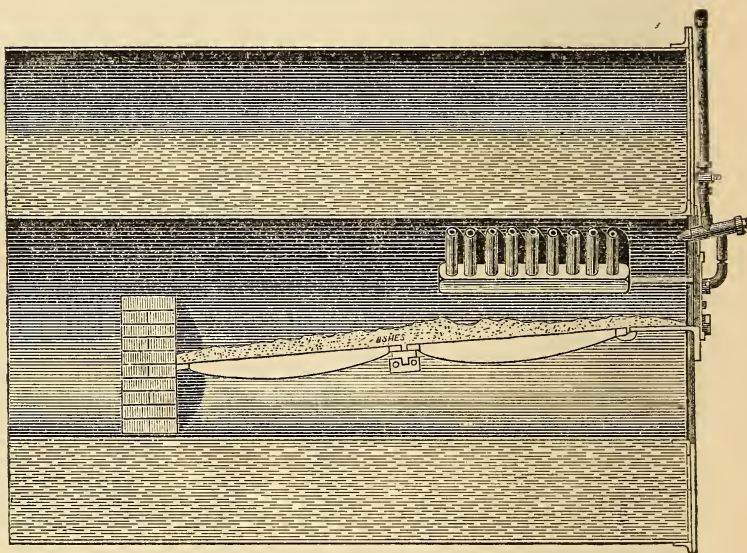


FIGURE 9.

Several years ago (1868) Messrs. Wise, Field and Aydon's system of burning liquid fuel was illustrated and described in the "*Engineering*." The evaporation reported as having been obtained in actual practice is so near the theoretical calorific power of the fuel, that it seems almost impossible to improve upon a process yielding such high results. The engravings, figures 9 and 10, show its application to a Cornish boiler; these

engravings, together with the descriptive matter accompanying them, are reproduced from the above journal:

"As will be seen from the engravings, the apparatus is a very simple character. It consists, in fact, merely of a super-heater arranged as shown, and a kind of

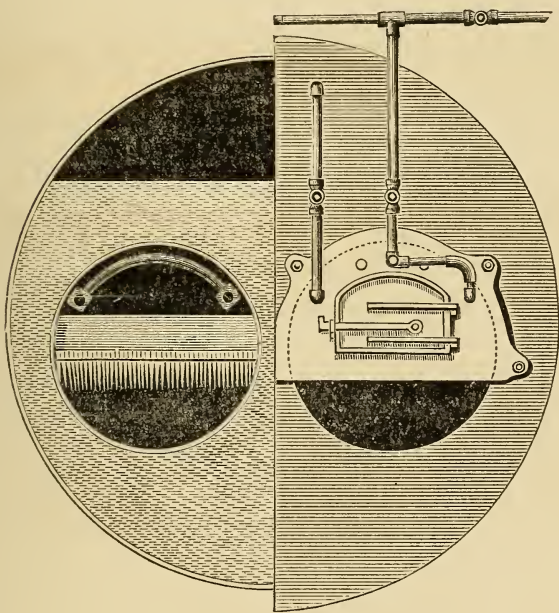


FIGURE 10.

injector placed in an inclined position just above the fire-door. The petroleum, or other liquid hydrocarbon, to be burnt, is led to the injector through a pipe furnished with a cock, by which the supply can be regulated, and it is there met by the steam which has passed through the super-heater, and which has thus had its temperature raised to about six hundred degrees. The

injector is very similar in its construction to Gifford's well-known instrument, and its action is such that the liquid fuel is injected into the furnace in the form of an exceedingly fine spray mixed with the super-heated steam. In the case of the arrangement shown in figure 9 the spray thus injected comes in contact with the hot ashes on the fire-bars, and is thus ignited; a combustion ensues which is very perfect, and which is under most complete control, the amount of flame being readily increased or diminished by regulating the quantities of liquid fuel and steam admitted to the injector. The air necessary to support combustion is admitted through openings in the fire-door, and so long as the apparatus receives the most ordinary amount of attention, the flame produced is perfectly smokeless.

“As the liquid fuel is injected by the aid of super-heated steam, it is evident that a supply of steam must be obtained before the apparatus can be brought into action. This being the case, the arrangement shown by figure 9 will in many instances be that which it will be most convenient to adopt. In this arrangement the fire-bars are retained, and steam can thus be got up by an ordinary fire in the usual way. So soon as a certain pressure of steam has been obtained, the ordinary fire can be allowed to die out and the injector brought into action, the ashes remaining from the ordinary fire serving to close the openings between the grate-bars and to ignite the spray of liquid fuel, as we have already explained. This arrangement is also convenient in cases where the boiler is worked sometimes with liquid fuel

and sometimes with coal. In this case, the steam for injecting the liquid fuel may be obtained at starting from a small auxiliary boiler heated by an ordinary fire, it being, of course, merely necessary to use this auxiliary boiler until steam has been raised in the main ones.

“Altogether the apparatus here described is the most simple and efficient that we have yet seen for burning liquid hydrocarbons. We have been informed, on what we consider reliable authority, that at Mr. W. C. Barnes’ chemical factory at Hackney Wick, where his apparatus has been for some time at work, 15,240 pounds of water have been evaporated in five hours by one of the boilers, by the consumption of eight hundred pounds of oil; or an evaporation of nineteen pounds of water per pound of oil. Taking into consideration that the pressure at which the boiler is worked is twenty-eight pounds, and that the temperature of the feed-water was 66° , this performance is equivalent to the evaporation at atmospheric pressure, from a temperature of 212° , of twenty-two pounds of water per pound of oil burnt. The fuel used is the waste product left from coal tar after the removal by distillation of the naphtha and light oils. It weighs about sixty-five pounds per cubic foot, and is a refuse material produced at the above factory. The apparatus is supplied with oil from a tank, which is in its turn fed from the upper part of another tank placed at a slightly higher level. This latter tank has a funnel-shaped bottom which receives the dirt or other heavy impurities deposited by the oil, a pipe being fitted to the lowest point

of the bottom, so that these impurities can be drawn off when necessary. The oil tank is also fitted with a coiled pipe through which steam can be blown in cold weather, or at other times if it should be necessary, to liquefy the oil. We have ourselves seen the apparatus in action at Mr. W. C. Barnes' factory, and can testify to the perfect combustion obtained by its use. It has also, we may mention, been applied, amongst other places, to the boiler of a steam launch now at Woolwich dockyard, and we understand that it has in this case proved equally successful.

“The question of to what extent liquid fuel can be economically substituted for coal, is one to which it is at the present moment very difficult to give even a general reply, whilst to give a precise answer is, of course, impossible. The question is, in fact, one upon which most persons proposing to use liquid fuel would have to decide for themselves. In every case the answer will depend greatly upon the comparative prices at which coal and liquid fuel can be obtained, and upon the certainty with which a supply of the latter fuel is procurable. In many instances the rate of evaporation, which we have above mentioned as having been obtained at Mr. W. C. Barnes' works, would be amply sufficient to justify the substitution of liquid fuel for coal, particularly where the fuel is obtainable in sufficient quantities close at hand as a waste product; whilst in other cases, where coal can be got at a very cheap rate, this latter fuel will have the advantage. Perhaps the nearest approach to a general answer which can be given to the

question is, that so long as the cost of a certain quantity of liquid fuel does not exceed, or only very slightly exceeds, the cost of the amount of coal or other solid fuel necessary for doing the same work, there is an advantage in using the liquid fuel, there being a saving effected in the wear and tear of fire-bars, etc., and the cost of labor for firing being very greatly reduced.

“So far we have only been speaking of land boilers. In the case of steamships, and particularly of war vessels, or steam yachts, the power of carrying fuel for an increased number of days’ consumption is one which, in many instances, will outweigh all questions of cost. In hot climates, also, the adoption of liquid fuel would materially add to the comfort of the stokers, as in cases where it was used it would be comparatively easy to maintain the stokehole at a moderate temperature. Another point, which is of importance in the case of both land and marine boilers is, that it appears certain, from the experiments which have already been made, that a greater duty can be got out of any given boiler when it is worked with liquid, than when it is worked with solid fuel; or, in other words, that with a given boiler a much greater quantity of water can be evaporated in a given time with the former fuel than with the latter.”

CHAPTER XVI.

GASEOUS FUEL.

Loss Attending the Use of Solid Fuels—Advantages Connected with the Use of a Gas-Fuel—Coal-Gas for Domestic Use—Water-Gas—Volume of Water-Gas Obtained for One Ton of Coal Burned—Strong's Process for Generating Fuel-Gas—Professor Gruner Quoted on the Great Waste of Heat in Several Metallurgical Processes—Comparison between the Efficiency of Crude-Coal and Water-Gas—Calorific Intensity of Water-Gas—Analysis of Water-Gas—Calorific Equivalent of Water-Gas—Flame Temperature—Economic Value of Water-Gas—Influence of the Specific Heat of the Products of Combustion of Water-Gas—Water-Gas as an Illuminating Agent—Objections to Water-Gas.

There is always a loss attending the generation of heat from solid carbonaceous fuels, and perhaps quite as much more heat is lost in its application to any economic use. The loss is greater in proportion as the amount of coal burnt becomes less in quantity. Perhaps there is no single application of heat in which the loss is greater than that applied to the melting of metals in crucibles. In this metallurgical operation the fire is often large, and urged to its utmost intensity, until the metal has reached the proper degree of fusion, when the crucible is removed and the fire abandoned. This will apply in almost any case where an intense heat is required, and its use confined to certain fixed or arbitrary working hours. In this respect liquid or gaseous fuels have an advantage over solid fuels, as they need not be lighted until the last moment, the nature of

the fuel permitting a concentration of heat at any desired point of application, and in any degree of intensity; it is also, at all times, under perfect control, and the supply may be instantly cut off when no longer required.

“Another cause of loss in the burning of crude fuels, and one of sufficient importance to deserve mention, is the fact that there is mixed with the carbon a considerable quantity of foreign matter not combustible, which absorbs heat and gives no equivalent. This is represented principally by the ash and clinker, which every consumer of coal knows to be a large item. It reaches from ten to fifteen per cent. of the material paid for. To illustrate the difficulties attending the use of a crude form of fuel, let us take the most familiar methods, such as are employed in domestic cooking and heating ($6\frac{1}{2}$).

“Ignoring the mechanical imperfections of stoves and furnaces, lest an examination into them should extend this article unduly, we will examine the more evident sources of loss:

“*a.* The expenditure of fuel in generating heat at times when it is not utilized. Every housekeeper must have been struck with the fact that a large amount of wood and coal is burned before the range is ready to cook, and that a probably larger amount still is used after the cooking is done. Annoying as this may be, it is cheaper to keep the fire up between meals, even in summer-time, when it is undesirable, than to let it go down and re-kindle three times.

"*b.* The *excessive quantity* employed while in use. Often to accomplish some trifling result, like the boiling of a tea-kettle, the whole area of fire space is necessarily kindled, though not more than one-tenth of it is required. Twenty pounds of good anthracite coal contain heat-energy sufficient to raise two hundred and seventy thousand pounds of water one degree in temperature, or seventeen hundred and seventy-six pounds from sixty degrees Fahrenheit to the boiling point, two hundred and twelve degrees Fahrenheit, and yet it is to be feared this power is frequently employed in cooking a pot of coffee. If we have expended for our morning draught heat enough, if perfectly applied, to raise three-fourths ton of the same liquid from atmospheric temperature to boiling point, it may be considered a somewhat luxurious beverage.

"*c.* The items of labor and inconvenience incident to the use of coal are too apparent to need any enlargement.

"These are the principal arguments against the general use of fuel in its natural condition, and they appear formidable enough to justify the assertion that not over ten per cent. of the heating power of such fuel is utilized.

"Let it be remembered that it is in all cases *gas only* that we burn, and from which we derive heat, so that the question is really whether each family can make a limited quantity of the gas as economically and successfully in very defective ranges and stoves, as the same or a much better article can be manufactured on a large

scale at some great establishment whence it could be distributed to consumers. There can be no doubt that the advantage possessed by all concentrated industries exists in this one to at least as great a degree as in any other department of manufacture. We might as reasonably expect to grind our own flour, or weave our own fabrics economically, as to successfully compete with large gas-works properly constructed and skillfully managed.

“The advantages connected with the use of a gas-fuel may be enumerated as follows:

“a. The cost, labor and inconvenience of handling a heavy material is avoided, the fuel being capable of easy distribution.

“b. It is in a form also free from those material impurities which involve a large residual waste, besides impairing combustion.

“c. It is free also (if it be a purely combustible gas) from those ingredients which, in the present methods of heating, involve even larger loss than the cause last mentioned.

“d. It is in precisely the condition to unite perfectly and instantaneously with the oxygen of the air, thus securing a thorough combustion.

“e. Hence it gives an immediate and uniform result, and its flame temperature is constant.

“f. The intense and steady heat of the flame just mentioned saves both time and money, by presenting an even fire-surface ready at the moment of ignition.

“*g.* It is a fire capable of concentration upon the precise point where the result is desired, and one that is thoroughly under control, the turning of a valve starting, graduating, or stopping the combustion at will.

“*h.* The general cleanliness of the system, no dirt or residuals being left.

“*i.* The decided advantage from a sanitary standpoint of simply *burning* combustible gases in our dwellings, instead of attempting to *make* them as well, by means of the imperfect gas machines called stoves. In the one case the only risk arises from the possibility of a leak, readily detected by the senses, and having simple mechanical remedies; in the other it is a much more serious risk, because the defect is a chemical one, consequent upon imperfect combustion, and the infusion of poison into the atmosphere is likely to be frequent and insidious, to say nothing of the deoxidation of the air by contact with red-hot iron surfaces. The reduction of this particular danger is about in proportion of the greater completeness of the combustion of the more refined fuel.

“These facts appear to be overwhelming arguments in favor of a gaseous, as against a gross form of fuel, and lead to the inquiry, what gases are available for such purposes?

“The ordinary coal-gas made for illuminating purposes possesses some of the requisite qualities. It is a combustible gas of great purity, of sufficiently low density to render its distribution easy, and with a high flame temperature; but, *per contra*, the constituents

which impart the illuminating power are expensive, while entirely unnecessary for fuel purposes. And yet, high-priced as it is, practical experience in its use proves that, in some departments at least, it is certainly cheaper than coal, besides its collateral advantages; and it is at the present time employed, to a limited extent, by those who have become familiar with the facts. Exceedingly interesting tests have been made by the London engineers with city gas, developing some economic features in the matter quite surprising; and at the meeting of the American Gas-Light Association, in 1877, a paper was presented by one of the members showing that careful experiments had so thoroughly demonstrated its saving, even at three dollars per one thousand cubic feet, that nine-tenths of his customers were using it in preference to wood or coal for kitchen and laundry purposes.

“Nevertheless, coal-gas can hardly be expected to offer, for general use—domestic and industrial—a substitute cheap enough to supplant coal. Something at a still lower price is needed. Such gas as is made by the Siemens process, before alluded to, has the advantage of cheapness, so far as the mere relation of cost and quantity is concerned, as it can be produced at about fifteen cents per one thousand feet, but its composition is not favorable. It in fact contains less than thirty per cent. of combustible gases, the remainder being worse than useless, besides rendering it too heavy for ready distribution at long distances.

WATER GAS.

“A water-gas—that is, a gas resulting from the decomposition of steam by contact with incandescent carbon—if it can be made cheaply, possesses those very qualities most desirable in a fuel, viz, inflammability and intensity.

“Composed of hydrogen and carbonic oxide, it is free from the undesirable element, nitrogen; and what an advantage lies in that single fact, it is hoped the foregoing explanation may have made measurably apparent. If carbonic oxide representing the maximum flame intensity (among practical gases), and hydrogen with but little less of this quality, and an even ‘greater useful value,’ as Percy expresses it, do not furnish the very highest order of fuel, then science does not yet know where to seek it. Fortunately, too, it is a fuel obtainable at the lowest cost, though this is a recent achievement. For more than half a century inventors of different nationalities have racked their brains for some method by which water-gas could be produced in large quantities inexpensively for the industrial arts, but various defects have invariably attached to the systems proposed and rendered them unsuccessful.

“It requires the outlay of great potential energy to release the hydrogen of water, but the Lowe apparatus, by a system at once original and simple, generates a concentrated and sustained heat which does the work with a facility that is astonishing, yielding a volume of fifty thousand feet for a ton of coal burned.

M. H. STRONG'S PROCESS FOR GENERATING FUEL GAS.

“Adopting the economic principle of interior combustion throughout, viz, burning the coal in a primary chamber, or generator, and the products of its partial combustion in a secondary one, wherein the heat is stored for subsequent utilization, there are novel features in the Strong process, which give it very definite advantages in the rapid and economic generation of a combustible gas of remarkable purity and efficiency for fuel purposes.

“Reference to the accompanying diagram, plate V, will make intelligible the following description of the apparatus and its operation:

“The generator is charged with lump coal or coke, entered at the door in its side, or from above through the opening left by the removal of the hopper Z, which is removable by means of a lever and tramway. An air-blast enters below the hydraulic grate-bars at W, which drives the fire and forces over into the adjoining chambers, laid up with loose fire-brick like a Whitwell stove, the products of partial combustion (Siemens gas), which are ignited therein by a second blast entering through a perforated tiling at X, and burn downward among the brick work, following the direction of the arrows. The third chamber, filled, like the second, with refractory material, absorbs a part, at least, of the heat of the waste products, which escape at the top through an open valve, shown in the diagram as closed.

“When the coal has attained a heat of say red to bright red, the brick of the super-heater (as the secondary chambers are termed) show orange to white.

“The air-blasts are then shut off, the valve before mentioned is closed as in the cut, and steam is admitted just below it at *Y*. Passing in the reverse direction of the arrows, it becomes intensely heated by contact with the bricks, from which it emerges into the top of the generator, where it meets at *V*, a shower of coal-dust sifted downward from the hopper *Z*, by means of an Archimedean screw slowly revolved.

“The steam has acquired such an increment of heat that, by contact with the dust-carbon, a mutual decomposition instantly ensues, and the gases resulting pass downward through the bed of coal and out below the grate-bars into a hydraulic main.

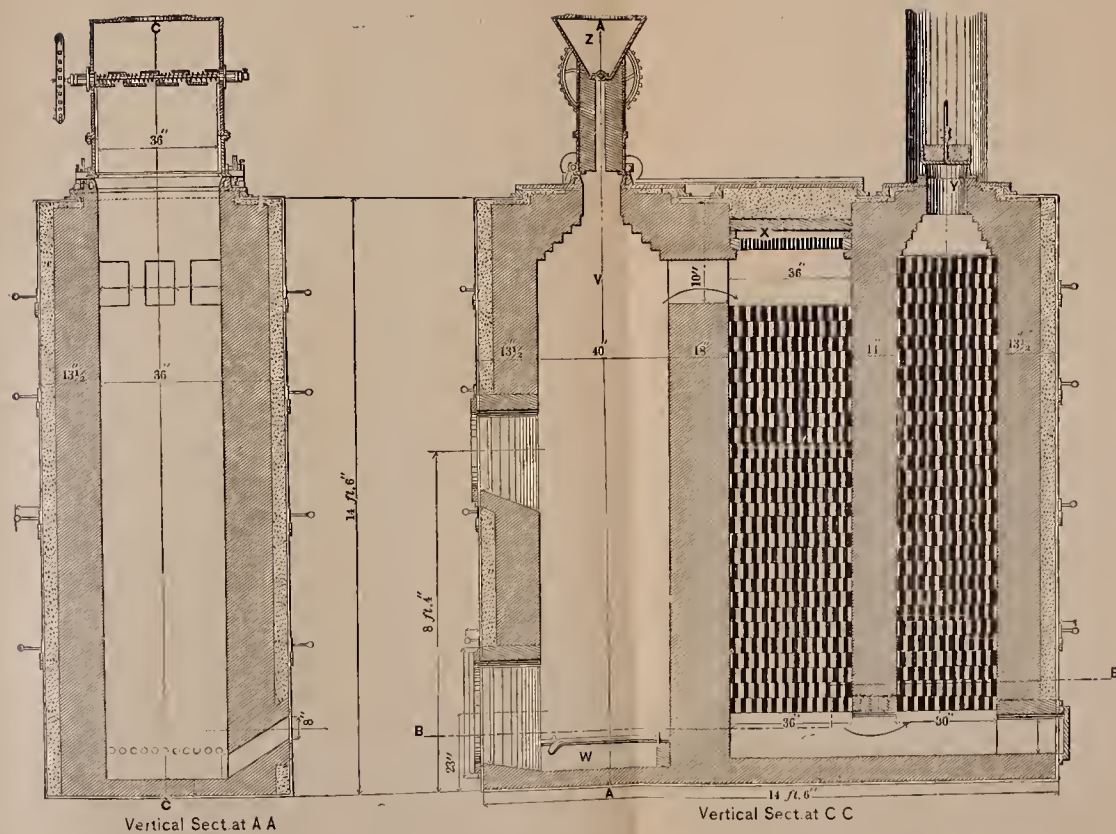
“Astonishing as this original method of decomposition may appear, there is no doubt of its occurrence at the point *V*, as during the earlier experiments the gases were allowed to escape from the generator without passing through the incandescent coal. There was found, however, an excess of carbonic acid in the product, and some unconverted particles of carbon were carried over. Both these defects were remedied by the passage of the gases through the burning coal, the carbonic acid changing to the oxide of carbon and the unburnt dust being arrested and utilized as fuel. The theory that the rapidity in evolution of the gas is proportioned to the reduced size of the carbon particles is fully confirmed by test made upon pulverized peat, dur-

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M. H. STRONG'S APPARATUS FOR GENERATING FUEL GAS.



ing which the volume of gas for a given period was increased about fifty per cent. as compared with the coal slack.

"The operations of the apparatus at Mount Vernon, in New York, where experimental practice has extended through the past year, substantiate the claim that a pure water-gas can be obtained at the expenditure of not over 2,240 pounds of coal for each 50,000 cubic feet. This includes the quantity burned under the boiler, which amounts to from twenty-five to thirty per cent. of the whole. But it would seem that this considerable amount expended in the generation of the steam, may be saved by a simple utilization of the heat of the alternating waste and gaseous products which, under those experiments, escaped at from 800° to 1,200° Fahr.

"It is confidently believed that if these hot gases were employed to heat the air-blast and the water, the product of combustible gas would be increased to from 65,000 to 70,000 cubic feet for each ton of coal.

"The most striking advantages of the Strong process are,

"1. The extreme rapidity with which the gases are generated in large volumes.

"2. The variety of materials which may be employed, and their low cost.

"3. The remarkable purity of the product.

"4. The economy of the labor involved.

"Regarding the first claim, it may be stated that a furnace of the dimensions shown in the diagram will deliver fully ten thousand cubic feet for each run of

thirty minutes. The alternate thirty minutes is used for re-heating, as in the Lowe process. A pair of such furnaces to secure continuity of operation, could be relied on to furnish nearly five hundred thousand cubic feet per day, and the labor requisite to run them would be but two men for each twelve hours.

“Not only can anthracite or bituminous coals be used but lignites and coke are available, and, what is very important, their culm or slack can be employed in the proportion of three-fourths, with very positive advantages. In fact, the ability of this system to utilize dust-carbon has been tested even to the successful use of peat, as already mentioned.

“It will be seen, therefore, that this method does not depend upon any special forms of material, but, on the contrary, employs many, some of which are abundant and inexpensive. In consequence of this and the advantage first mentioned, the gas can be produced at the lowest possible price.

“The extraordinary purity of the gas derived by this system is another exceedingly important fact. Analysis by Dr. Gideon E. Moore prove that the unpurified gas contains only 12.90 grains of sulphur, which is considerably less than the legal limitation for the purified gas furnished to London. But the absence of any large percentage of non-combustible constituents is far more important, as will be observed by the following table:

Oxygen.....	0.77
Carbonic acid.....	2.05
Nitrogen.....	4.43
Light carbonic hydrogen.....	4.11
Carbonic oxide.....	35.88
Hydrogen.....	52.76

“The relatively small proportion of N and CO₂ will undoubtedly be reduced yet lower by an apparatus on a larger scale than the one in use at Mount Vernon, as the residual air left in the stack at the time of shifting from the blast to gas-making would be proportionately smaller, and this is the principal source of these non-combustibles.

“It will be apparent that this composition represents the best mixture for calorific purposes known to science. It is in striking contrast to that produced by the Siemens furnace, which, at about the same cost, contains about two-thirds of non-combustibles. This serious drawback has been a characteristic of all other cheap gases heretofore, and is a fatal objection in any method aiming to supply the general demands of a fuel gas. Aside from the fact that such a heavy dilution impairs the efficiency and value of a gas to an extent not generally understood, the addition of such a useless volume would necessitate an excessive size and cost of mains for its distribution.

“It becomes necessary here to explain a popular misconception which has led many intelligent minds to an entirely false conclusion regarding the economic advantages of gaseous forms of fuel as compared with crude

ones. It grows out of the axiom that in the conversion of the steam and carbon into their resulting gases there is an inevitable expenditure of thermal force, so that the new form of fuel represents less theoretic units of heat than the old, and that, in consequence, there is a loss rather than a gain by the exchange.

“This is undeniable, but it is surprising that it should be so often misapplied in practical calculations, because *the comparison lies between the two forms of fuel, not upon their mere theoretic calorific values, but upon the useful effects obtainable from each in practice.*

“The plain business question which presents itself, therefore is, what advantage does the Strong gas possess over the coal from which it was produced in actual operations? Let us investigate this carefully.

“The standard principle for obtaining the calorific or heating power of any fuel is to ascertain how many weights of water one weight of it will raise one degree of temperature, if burned under the best possible conditions in air—and the number of weights so determined are called the heat-units of that fuel. These of course symbolize its maximum calorific power. Thus, dried peat is said to possess nine thousand nine hundred and fifty-one units of heat; asphalt, sixteen thousand six hundred and fifty-five; good anthracite, thirteen thousand per pound. That is, the total heat of the perfect combustion of one pound of anthracite would raise thirteen thousand pounds of water one degree Fahrenheit. But in estimating the practical heating power of these and other substances we must remember

that it is not possible to obtain a result even remotely approaching these figures, because instead of burning them upon nicely adjusted laboratory principles, our ordinary methods of combustion are grossly imperfect and extremely wasteful. An explanation of the why and wherefore of this would be interesting did the limits of this article permit, but a statement of the fact with some authoritative comments thereon must suffice. Professor Gruner, in a paper of which the following abstract was published in the *Engineering and Mining Journal*, volume twenty-one, number eight, states that:

“In the wind-furnace, which is, from this point of view, the most imperfect apparatus, there is utilized, in the fusion of steel in crucibles, but 1.7 of the total heat capacity of the fuel, or at most three per cent. of the heat generated. In the reverberatory, when steel is melted in crucibles, the useful effect is two per cent. of the total heat, or three per cent. of the heat generated. In the Siemens crucible furnaces, 3 to 3.5 per cent.; in Siemens glass furnaces, operating on a large scale, 5.50 to 6 per cent.; in ordinary glass furnaces, three per cent.; in fusion upon the open hearth of a reverberatory, of glass, seven per cent.; of iron, eight per cent.

“In well-arranged Siemens and Ponsard furnaces, up to fifteen, eighteen and even twenty per cent. of the total heat is utilized. The calorific effect is much greater when the fuel is mixed with the material to be fused. Large iron blast furnaces utilize according to their working, seventy to eighty per cent. of the heat generated, or thirty-four to thirty-six per cent. of the

total heat which the complete combustion of the fuel would set free.'

"We are thus furnished a basis of comparison between the efficiency in actual practice of crude coal and water-gas, for it is estimated that by reason of its instant mixture with the oxygen of the air, the combustion of the gas is so perfect that the heat generated would be ninety per cent. of the full theoretic power by any rational system which would use the available heat in the products of combustion.

"Therefore, while 2,240 pounds of coal represent a total theoretic value of 29,120,000 heat-units, the value really utilized by the best modern blast furnace, according to Professor Gruner (thirty-six per cent.) would be 9,483,200.

"The weight of gas which the same ton would produce, viz, two thousand and fifty pounds, possesses a total value of 18,035,900 heat-units, of which 16,232,310 are actually available in practice, showing an advantage of the new fuel against the old as 1.71 is to 1. This advantage, moreover, exists upon the basis of a similar price for the coal employed in the two cases, while in fact there is a still further gain in favor of the gas, owing to the fact that it makes available a much cheaper material (slack) than can be employed in the direct furnace operation—a difference at tide-water of about 2.5 to 1.

"The comparison becomes still more favorable to the gas fuel if applied to ordinary domestic uses. In that department, it is generally conceded that ten per

cent. of the theoretic heating power of coal is the best result obtained, so that in these uses the gas would have an advantage of about 5.57 to 1.

"Let us now, for convenience, write down not the theoretic, but the *practical, available heat-units* side by side for comparison, as we have ascertained them above.

	ONE LB. COAL. (THEORETIC UNITS 10,000.)			STRONG GAS FROM 1 LB. COAL. = $\frac{205}{224}$ LB. GAS. (THEORETIC UNITS 8.798 PER LB.)
	CRUCIBLE FURNACES.	LARGE BLAST DO.	DOMESTIC USE.	IN EITHER USE.
Per cent of heat utilized.....	3½	36	10	90
Units available in practice.....	455	4,680	1,300	7,246

"This allows ten per cent. loss in the combustion of the gas, which is the probable extent of this waste. In some metallurgical operations a further allowance may be necessary to cover an imperfect utilization of the escaping products, but as this loss is variable with different methods we leave the computations to the reader.

"This, it is insisted, is the proper method of estimating the actual relative thermal values of the two forms.

"Beyond this first economic gain are collateral ones, affecting not only cost but other equally important questions of time (which is a synonym for money) and the quality of the products. Take, for example, the advantage of a fuel which can be turned on by a valve, lighted on the instant, and extinguished as quickly. Aside from the tedious time necessary to the firing up of a metal furnace, an element of expense, how largely

the labor incident to the care of such operations would be reduced.

“Another feature worthy of special comment is the intensity of combustion of a gas fuel. The theoretic power of the Strong gas is 5483° Fahr., and the relation of this fact to rapid and economic operation is too manifest to require argument. A furnace will often stand indefinitely at a temperature just short of that required to accomplish its work, at an incalculable loss of time, money and temper, and sometimes to the serious disadvantage of the product. The writer has seen a small experimental reverberatory for the burning of this gas ready to charge in twelve minutes from lighting, and iron melted therein in eight minutes thereafter.

“Again, the constancy of this gas flame is another very marked advantage, and will enable the mechanic, once the proper admixture of air is ascertained, to yield a heat adapted to his special wants; to maintain a uniform temperature and obtain a uniform result in time, cost and quality.

“The whole subject is one of peculiar interest and opens many avenues of inquiry and experiment.”

The following is a copy of a report by Dr. Gideon E. Moore on water gas as made by the apparatus and process just described. He visited the gas works at Mount Vernon, N. Y., October, 1877, obtaining samples of the gas, which were analyzed by him, with results as given below.

This report is an interesting contribution to the literature of gaseous fuel, and though repeating much

that has already been said and explained in the earlier chapters of this book, it is deemed best for the sake of clearness and comparison to print the report without alteration or erasure, which is as follows:

"The gas was made on the day previous to my visit, and I was assured by Mr. Strong that no lime had been used, nor other purifying agent except the water in the hydraulic main. The gas was allowed to pass freely from the gasholder through a series of glass tubes for two hours, to displace the air, after which the tubes were hermetically sealed by melting the ends, and the gas preserved in this state until required for use.

"The specific gravity of the gas was determined by direct weighing. The analysis was made by the methods laid down in Bunsen's gasometry, the more important determinations being made in duplicate—the carbonic oxide, for instance, being determined both by eudiometric analysis and by absorption with cuprous chloride.

"The specific gravity of the dry gas was found to be 0.5408, air being unity, whence one cubic foot weighs 0.04116 pound. The composition by volume was found to be as follows, viz:

Oxygen.....	0.77
Carbonic acid.....	2.05
Nitrogen.....	4.43
Carbonic oxide.....	35.88
Hydrogen	52.76
Marsh gas.....	4.11
	<hr/>
	100.00

"Had the carbonic acid been completely reduced to carbonic oxide, the gas, after deducting the 0.77 per cent. of oxygen and 2.91 per cent. of the nitrogen as air, would have presented the following composition, viz:

Nitrogen.....	1.55
Carbonic oxide.....	40.64
Hydrogen.....	53.63
Marsh gas.....	4.18
	<hr/>
	100.00

"It is interesting to compare these figures with the theoretical result of the action of steam on anthracite coal.

"According to Percy, the combustible portion of Pennsylvania anthracite consists of

Carbon.....	94.63
Hydrogen.....	2.73
Oxygen.....	1.28
Nitrogen.....	1.36
	<hr/>
	100.00

" If we assume that the 2.73 parts of hydrogen are evolved in combination with 8.19 parts of carbon in the form of marsh gas, 100 parts of anthracite, free from ash, would require for the complete conversion of the residual, 86.44 parts of carbon to carbonic oxide $115.25 - 1.28 = 113.97$ parts, by weight, of oxygen or 128.22 parts of water. The gaseous products of the transformation of one hundred pounds of pure anthracite would, therefore, be,

Nitrogen.....	1.36
Carbonic oxide.....	201.69
Hydrogen.....	14.25
Marsh gas.....	10.92
	<hr/>
	228.22

or, reduced to per centages,

	BY WEIGHT.	BY VOLUME.
Nitrogen.....	0.60	0.32
Carbonic oxide.....	88.38	47.89
Hydrogen.....	6.24	47.25
Marsh gas.....	4.78	4.54
	<hr/>	<hr/>
	100.00	100.00

" On comparing these figures with the analysis of Strong's gas, it will be seen that the proportion of marsh gas is virtually identical in both cases, showing that it must have resulted solely from the destructive distillation of the coal, and not by direct synthesis. The gas formed by the action of superheated steam on charcoal possesses, according to Bunsen, the composition,

Carbonic acid.....	14.65
Carbonic oxide.....	29.15
Hydrogen.....	56.03
Marsh gas.....	.17
	<hr/>
	100.00

" It will be observed that the amount of carbonic oxide in Strong's gas falls somewhat short of the theoretical proportion, while there is a corresponding excess of hydrogen. This is attributable partly to the absorption of oxygen in the oxidation of metallic sulphurets in the coal, partly to the formation of carbonic acid and its retention in the ash or removal by solution in water, perhaps partly also to the presence of oxidized products in the small proportion of tar.

"On the twenty-eighth of December I made a careful sulphur determination on gas made in my presence, and taken as it flowed from the scrubbers to the gasholder; no other purification having been employed. The gas was found to contain 12.96 grains of sulphur to the one hundred cubic feet—an amount surprisingly small, at first sight, but less so when we consider that the two products of the action of steam on highly heated sulphurets, viz, Sulphureted hydrogen and sulphurous acid immediately re-act on each other with the formation of free sulphur and water. It is, therefore, evident that the sulphureted hydrogen in the gas is simply the excess over that which is decomposed by the sulphurous acid, and that this, must, at the most, be small in amount is equally evident from the fact that anthracites are, as a rule, much freer from sulphur than bituminous coal, and that they are especially free from the organic sulphur compounds which, by destructive distillation, yield the volatile sulphur compounds so difficult of removal from ordinary coal gas. The sulphureted hydrogen in the Strong gas is easily removable by the simplest means.

CALORIFIC ELEMENTS OF THE STRONG GAS.

"*Calorific Equivalent*—The theoretical calorific equivalent or heating power of combustibles, is the amount of heat evolved by the combustion of the unit of weight thereof, expressed by the number of units of weight of water which can thereby be raised in temperature one degree on the thermometric scale.

"In England and America the unit of weight is the avoirdupois pound, the measure of temperature the Fahrenheit thermometer. One unit of heat, therefore, is the quantity of heat which will raise the temperature of one pound of water one degree on the Fahrenheit scale, and n units of heat the amount which would be required to raise n pounds of water one degree Fahrenheit in temperature, or one pound of water n degrees.

"In the case of a compound combustible, or, more properly, a mixture of several combustible substances, like the Strong gas, the theoretical calorific equivalent is obtained by multiplying the weights of the different ingredients, expressed as decimals of a pound, by their several calorific equivalents as previously determined by experiment. The sum of the numbers so obtained expresses the theoretical calorific equivalent of the mixture. In the following computations I have taken as a basis the fig-

ures of Favre and Silberman, whose experimental researches are the most exact we possess.

"Applying these principles to the analysis of the Strong gas, we have,

	COMPOSITION IN DECIMALS OF 1 POUND.		CALORIFIC EQUIVA- LENTS.	
Oxygen.....	0.01740	x	0.0	= 0.0
Carbonic acid.....	0.06372	x	0.0	= 0.0
Nitrogen.....	0.08798	x	0.0	= 0.0
Carbonic oxide.....	0.70969	x	4325.4	= 3069.7
Hydrogen.....	0.07473	x	62031.6	= 4635.1
Marsh gas.....	0.04648	x	23513.4	= 1092.9
	<u>1.00000</u>			<u>8797.7</u>

Hence the theoretical calorific equivalent of the Strong gas is 8,798 units of heat.

FLAME TEMPERATURE.

"By the flame temperature is understood the temperature prevailing in the interior of a burning mixture of gases. It may be computed from the calorific equivalents when the specific heat of the gaseous products of combustion is already known. The result is very different, according as the mixture burns under constant pressure, or with constant volume. The first case is the only one of which we have here to treat.

"At 62° Fahrenheit one cubic foot of the Strong gas weighs 0.04116 pound, and requires for its perfect combustion 2.47 cubic feet of air, weighing 0.1880 pound. Proceeding to the computation of the calorific equivalent of one pound of the mixture of air and gas in these proportions, we have,

	COMPOSITION IN DECIMALS OF 1 LB.		CALORIFIC EQUIVA- LENTS.	
Nitrogen	0.6557	x	0.0	= 0.0
Carbonic acid	0.0105	x	0.0	= 0.0
Oxygen.....	0.1964	x	0.0	= 0.0
Carbonic oxide	0.1174	x	4325.4	= 507.6
Hydrogen	0.0124	x	62031.6	= 766.5
Marsh gas	0.0076	x	23513.4	= 176.9
	<u>1.0000</u>			<u>1451.0</u>

whence the calorific equivalent of the mixture is 1451.0 units. The specific heat of the products of combustion results from the following considerations, viz:

	COMPOSITION IN DECIMALS OF 1 LB.		SPECIFIC HEAT.	
Nitrogen	0.6557	x	0.2440	= 0.15999
Carbonic acid.....	0.2160	x	0.2164	= 0.04676
Water vapor.....	0.1283	x	0.4750	= 0.06092
	1.0000			0.26767

whence the specific heat of the products of combustion is 0.26767. Dividing by this, the calorific equivalent previously found, we have

$$1451.0 \div 0.26767 = 5420.9^{\circ} \text{ Fahr.},$$

the theoretical elevation of temperature by combustion above the initial temperature of the combustible mixture. If this initial temperature be sixty-two degrees Fahrenheit, the theoretical temperature of the flame will be

$$5420.9 + 62 = 5482.9^{\circ} \text{ Fahr.}$$

"This temperature lies beyond the point at which dissociation commences, and hence would never be attained in practice, as, however, Bunsen* has shown that the percentage of dissociation increases from the point at which it commences, through the higher temperatures, being for instance, in the case of a mixture in equivalent proportions of hydrogen or carbonic oxide and oxygen, fifty per cent. at $2,000^{\circ}\text{C.} = 3,632^{\circ}\text{F.}$ and $66\frac{2}{3}$ per cent. at $3,000^{\circ}\text{C.} = 5,432^{\circ}\text{F.}$, we may safely assume that in the case of different gases the temperatures attained in practice will be, within certain limits, proportional to their respective theoretical flame temperatures. The experiments of Bunsen show that the extreme temperature which may be attained by the oxyhydrogen blast will not exceed $5,432^{\circ} \text{ Fahr.}$ According to H. Valerius† the theoretical flame temperature of ordinary illuminating gas in pure oxygen is $13,509^{\circ} \text{ Fahr.}$, whereas in air it is $4,588^{\circ} \text{ Fahr.}$, or about $900^{\circ} \text{ Fahr.}$ below that of the Strong gas.

"It is hardly necessary to add that dissociation of the products of combustion only affects the *temperature* of the flame, and has nothing to do with the *quantity* of heat evolved during the combustion.

ECONOMIC VALUE OF THE STRONG GAS.

"In the consideration of the economic value of the Strong gas the two applications which pre-eminently demand our attention, are,

*Poggendorff's Annalen, CXXXI., 171.

†Les Applications de la Chaleur.

"1. Its value as a substitute for other forms of gaseous or solid fuel, in the arts and for domestic use.

"2. Its application for illuminating purposes either, after previously charging it with illuminating substances, as a substitute for ordinary illuminating gas, or as a diluent for very rich coal gas.

"Taking these subjects in the order I have indicated, I first pass to the consideration of

"*The Comparative Value of the Strong Gas as Fuel*—As has already been shown, the Strong gas possesses a heating power of eight thousand seven hundred and ninety-eight units, and a flame temperature of 5,483° Fahr. One cubic foot of the gas, weighing at 62° Fahr., 0.0411 pound requires for its perfect combustion 2.47 cubic feet of air, and yields 3.027 cubic feet of products of combustion, of which 0.610 cubic feet is aqueous vapor, and 2.417 cubic feet permanent gases.

"In the combustion of gaseous fuel, under normal conditions, and with perfect utilization of the heat of the fire gases, the only loss of heat is from radiation. Allowing ten per cent. as the probable extent of this waste, we have, for the effective heating power of the Strong gas—seven thousand nine hundred and eighteen units per pound, or one hundred pounds of pure anthracite, yielding, as has previously been shown, 228.22 pounds of gas, would develop in practice a heating effect equal to $228.22 \times 7,917.91 = 1,807,025$ units of heat. The theoretical heating effect of coal being thirteen thousand units, the one hundred pounds of coal would, if directly burned, develop one million three hundred thousand units, of which, however, but about fifty per cent., or six hundred and fifty thousand units, would be realized under ordinary conditions in practice, hence the practical heating effect of the gas stands to that of the coal from which it was *directly* derived as 2.78 to one, whereby it is, of course, assumed that no loss of gas has been experienced during the manufacture.

"In the manufacture, however, there is a large consumption of coal for heating the generator and for the production of steam. According to the inventor's figures, fifty pounds of coal will produce one thousand cubic feet of gas, weighing 41.16 pounds, and possessing the theoretical heating effect of three hundred and sixty-two thousand one hundred and thirteen units, of which three hundred and twenty-five thousand nine hundred and two units would be realized in practice. Fifty pounds of coal possesses the

theoretical heating effect of six hundred and fifty thousand units, of which but three hundred and twenty-five thousand would be realized in practice under ordinary conditions and by *continuous use*, as in the generation of steam. Hence, in practice, and under equal conditions as to radiation and continuous use, the gas will produce the full heating effect of the coal consumed in making it.

"The cost of the gas being, according to Mr. Strong's estimate, from six to eight cents per one thousand cubic feet, and the cost of anthracite being but one dollar and a half per ton for 'pea and dust' coal, the cost of the coal required would be but $3\frac{1}{2}$ cents, whence, assuming that there can be realized from such coal fully fifty per cent. of the theoretical heating effect, it follows that for such purposes as the generation of steam with blast air and continuous firing the Strong gas could not compete with such coal.

"The case is, however, very different in the very numerous class of applications, in which the cheapest grades of coal can not be used. Thus, with ordinary steam and manufacturing coal, of which the price at New York is at present four dollars and a half per ton, the fifty pounds of coal would cost ten cents, which, contrasted with the average cost of the Strong gas, seven cents, shows the great economic advantages of the latter. The advantages of gaseous fuel become still more strongly apparent when we consider that in a very large number of cases the amount of heat which coal is capable of affording is but imperfectly utilized, and that, in fact, owing to the intermittent use of the heat, but a small proportion of the theoretically available fifty per cent. is ever attained. It is safe to say that for domestic use the cost of the Strong gas would be at most but fifty per cent. of the cost of coal fires, and in summer even less.

"The only other forms of gaseous fuel with which the Strong gas can be compared are coal gas and the Siemens gas.

"While the theoretical heating effect of coal gas, viz, twenty-two thousand units, is about two and a-half times that of the Strong gas, the great cost of the former places it practically out of competition.

"Concerning the Siemens gas we have the following data on authority of Percy.* The average composition by volume of the gas at St. Gobian is,

* Metallurgy, Revised Edition, I., p. 528. I accept Percy's statement of the yield of the Siemens gas with great reserve. Except on the assumption that there has been an enormous loss during the process of manufacture, his estimate is much too low. As the statement, however, appears never to have been contradicted, I have employed it in default of more exact data for comparison.

Hydrogen	7.50
Carbonic oxide	17.00
Carbonic acid.....	6.59
Nitrogen.....	69.00
	<hr/>
	100.00

and it possesses, according to Percy, the average specific gravity, 0.78. One cubic foot at sixty-two degrees Fahrenheit, would therefore weigh 0.059 pound. The theoretical heating effect deduced from the foregoing analysis is 1101.1 units of heat per pound.

"According to Percy, one ton of coal, free from ash, will yield fifty-thousand cubic feet of gas. Assuming the coal to contain five per cent. of ash, one thousand cubic feet of the Siemens gas would require for their production forty-seven pounds of coal, and as one thousand cubic feet weigh 59.38 pounds, we have $59.38 \times 1101.1 = 65,383.3$ units as the heating power, compared with the 340,386 units afforded by the nine hundred and forty cubic feet of the Strong gas obtained from forty-seven pounds of coal. If, therefore, we assume that the Siemens gas has been made from coal at \$1.50 per ton, and if we leave out of account the cost of labor, repairs and all other items of incidental expenditure, we have, as the cost of the 65,383 units of heat of the Siemens gas $3\frac{15}{100}$ cents, while one thousand cubic feet of the Strong gas, costing seven cents, will yield 362,113 units, or, in other words, taking as the cost of the Siemens gas the cost of the coal required to produce it, and allowing for the Strong gas the inventor's estimate, deduced from actual experience, of the total cost of production, the cost of a given quantity of heat obtained from the Siemens gas is to that of the same quantity obtained from the Strong gas in the proportion of 2.5 to 1.

"The theoretical elevation of temperature produced by the combustion of the Siemens gas is, as deduced from the foregoing analysis, 2,592 degrees Fahrenheit, or, with the air and gas at the initial temperature of 62° Fahr., the temperature of the flame would be 2,654° Fahr.

"One cubic foot of the Siemens gas requires 0.58 cubic foot of air for its perfect combustion, and yields 1.46 cubic feet of products of combustion, of which 1.39 cubic feet are permanent gases.

"For every one thousand cubic feet of gaseous products of combustion from the Siemens gas, there are developed 44,648 units of heat.

"For every one thousand cubic feet of products of combustion from the Strong gas, there are developed 119,635 units of heat.

"Hence, for the production of a given quantity of heat, there is formed with the Siemens gas 2.68 times the volume of gaseous products that would result from the use of the Strong gas.

INFLUENCE OF THE SPECIFIC HEAT OF THE PRODUCTS OF COMBUSTION OF THE STRONG GAS.

"In the foregoing estimates, I have assumed that the products of combustion of the Strong gas have been entirely deprived of their available heat, as would be the case in a rational system of practice, wherein the waste heat of the fire gases is used to heat the blast, or, in the case of the generation of steam, the feed water for the boilers.

"In the limited number of cases where this can not be done, other factors must be included in the calculation, whereby the result is to some extent modified, viz, the latent heat of vaporization of the water contained in the products of combustion, and the specific heat of the permanent gases therein.

"This correction becomes of special importance in the consideration of the question of a direct comparison between the Strong gas and other forms of fuel, such as coal and the Siemens gas, in the combustion of which a much smaller amount of aqueous vapor is formed.

"Selecting, for illustration, the simplest conditions under which the problem could present itself, we will take the case where the products of combustion leave the chimney at the temperature of two hundred and twelve degrees Fahrenheit.

"In our previous study of the conditions of combustion, I have assumed that the fire gases have been cooled down to the normal temperature of sixty-two degrees Fahrenheit, the temperature at which the air and gas were presented for combustion.

"One pound of the Strong gas contains,

Oxygen.....	0.0174
Carbonic acid.....	0.0637
Nitrogen.....	0.0880
Carbonic Oxide.....	0.7097
Hydrogen.....	0.0747
Marsh gas.....	0.0465
	<hr/>
	1.0000

and requires for its perfect combustion 5.9052 pounds air, yielding 6.9052 pounds of products of combustion. On multiplying the weights of the several products of combustion by the number of

units of heat required to raise one pound thereof from 62° to 212° Fahr., we obtain the following result, viz:

Nitrogen.....	$4.6593 \times (150 \times .2240 = 33.60) = 156.55$
Carbonic acid.....	$1.4690 \times (150 \times .2164 = 32.46) = 47.68$
Water.....	$0.7769 \times (150 \times 1.0000 = 150.00) = 116.53$
	<u>6.9052</u>
Latent heat of the vaporization of the water.....	$0.7769 \times 966 = 750.45$
Heat units retained by fire gases at 212° Fahr.....	<u>1,071.24</u>

Whence we have,

Calorific equivalent of Strong's gas.....	8,798 units
Latent heat of waste gases at 212°	<u>1,071 units</u>
Utilized	<u>7,727 units</u>

or, of the total heating power of the gas there is,

Wasted	12.18 per cent.
Utilized.....	<u>87.82 per cent.</u>
	<u>100.00</u>

"Let us see how the Siemens gas behaves under similar conditions. One pound contains

Nitrogen.....	0.7140
Carbonic acid.....	0.1053
Carbonic oxide.....	0.1752
Hydrogen	<u>0.0053</u>
	<u>1.0000</u>

and requires for its perfect combustion 0.6380 pound of air, yielding 1.6380 pounds of products of combustion. Proceeding, as before, we have,

Nitrogen	$1.2079 \times (150 \times .2240 = 33.60) = 40.59$
Carbonic acid.....	$.3806 \times (150 \times .2164 = 32.46) = 12.37$
Water.....	$.0495 \times (150 \times 1.000 = 150.00) = 7.43$
	<u>1.6380</u>
Latent heat of vaporization of the water, $0.0495 \times 966 =$	<u>47.82</u>
Heat units retained by fire-gases at 212°	<u>108.21</u>

Whence we have,

Calorific equivalent of Siemens gas.....	1101.1
Latent heat of waste gases at 212°	<u>108.2</u>
Utilized	<u>992.9</u>

or, of the total heating power of the gas, there is,

Wasted	9.82 per cent.
Utilized.....	<u>90.18 per cent.</u>
	<u>100.00</u>

"On the assumption, therefore, that the water formed by combustion is allowed to escape as *steam*, at 212° Fahr., the percentage of loss of heating effect from the latent heat of the fire gases is theoretically slightly greater in the case of the Strong gas than in that of the Siemens gas. In practice, the unavoidably large excess of air required for the combustion of the Siemens gas would cause the comparison to result decidedly in favor of the Strong gas.

"The application of water-gas in metallurgy is not new. We are, on the contrary, informed by Percy,* that the gas produced by the old and costly method of causing steam to re-act on coke in cast iron retorts was seen by him in operation for several years, at the Oldbury furnaces, near Birmingham, and that its use had been commenced in the Yorkshire blast furnaces.

"The special advantages of the Strong gas for use in metallurgy are, apart from the question of economy, the high and easily regulated temperature it affords, and the relatively small volume of products of combustion compared with the heating effect. It is, in fact, the most concentrated form of gaseous fuel hitherto attainable for this application.

APPLICATION OF THE STRONG GAS FOR ILLUMINATING PURPOSES.

"The Strong gas possesses two very valuable attributes as regards its application for illuminating purposes, either when used alone after charging it with illuminating hydrocarbons or as a diluent for very rich coal gas—the temperature of the flame, namely, and the heating power. As I have already shown, the flame temperature is some nine hundred degrees Fahrenheit higher than that of coal gas, while the *quantity* of heat evolved during combustion is to that from coal gas in the proportion of one to 2.5. This proportion would, of course, be somewhat changed after the gas had been charged with illuminating substances, but in any event, with equal illuminating power, it will prove comparatively free from the tendency to heat the air of the rooms in which it is burned, which is one of the grave objections to ordinary coal gas.

"The superior freedom of the Strong gas from sulphur is an extremely valuable property for illuminating purposes.

"The question naturally arises here, whether the use of a gas containing, as shown by analysis, as much as thirty-six per cent. of carbonic oxide, and which, under certain circumstances, might pos-

* Metallurgy, 1861, I., p. 203.

sibly contain from forty to forty-five per cent., would not be attended with danger to the health of the consumer.

"Leaving out of account the fact that there is even now some difference of opinion as to the precise nature and extent of the constitutional effects of air impregnated with a small proportion of carbonic oxide, it would be obviously absurd to base any estimate on the poisonous nature of the pure gas, or even on the proportion contained in the Strong gas. The question can only be decided by comparison with our previous experience with other illuminating gases of known composition.

"Were carbonic oxide the only poisonous ingredient in coal gas there might appear to be some foundation for the reasoning of the opponents of such gases as the Lowe gas, that if coal gas, which may contain as much as fifteen per cent. of carbonic oxide, be poisonous, a gas which may contain thirty per cent. must necessarily be twice as much so. Unfortunately for this chain of reasoning, carbonic oxide is not the only, or even the most, poisonous ingredient in coal gas. The heavy hydrocarbons, especially the vaporized tarry substances, may produce, when mixed even in slight proportion with the air, vertigo, insensibility and even death. According to Jacobs* the contents of as much as three (3) per cent. of coal gas in the air of a room is fatal to human life. If we accept the still smaller proportion of one per cent. of carbonic oxide as the minimum quantity required to produce an injurious effect, then fully three per cent. of such a gas as the Lowe gas would have to be present, whence it follows that the amount of such gas necessary to produce an injurious effect would practically amount to a fatal dose of ordinary coal gas.

"The absurdity of claiming that a gas containing as much as twenty-five to thirty per cent. of carbonic oxide is necessarily dangerous, will best be apparent from the consideration of the amounts contained in *wood* gas—a material largely used wherever the relative cost of wood and coal renders it economically advantageous. I give below the proportions of carbonic oxide found in different kinds of wood gas:

KIND OF GAS.	CARBONIC OXIDE.	ANALYST.
Not specified.....	61.79	Pettenkofer.
Crude.....	37.62	Pettenkofer.
Crude.....	23.21	Pettenkofer.
From Beech Wood.....	41.94	Reissig.
From Birch Wood.....	35.99	Reissig.
From Pine Wood.....	38.25	Reissig.
From Turf.....	20.33	Reissig.

* Quoted in Stohmann-Muspratt's *Chemie*, 3d Ed., IV., 623.

"In the year 1862, the following European towns were lighted with wood gas, viz, Coburg, Wurzburg, Darmstadt, Giessen, Zurich, St. Gall, Schaffhausen, Aarau, Lucerne, Regensburg, Landshut, Erlangen, Uhm, Kempton, Linz, Chur, Freiburg (in Switzerland), and many others. I have been unable to find that the question of possible danger from the presence of carbonic oxide in wood gas has ever been raised.

"*The objections to water gas* in general on account of its contents in carbonic oxide are based on an entire misconception of the meaning of the reports of the eminent scientific men who were called to pronounce upon the question of its safety in France. The French report was unfavorable for the following reasons:

"The gas was not saturated with illuminating hydrocarbons and was consequently *inodorous*; it was not of itself luminous, but was employed to heat to intense whiteness small cages of platinum, which were suspended in the flame and furnished the luminous body. Being inodorous, the escape of the gas could not have been detected, hence the dangers arising from accidental leakage were excessive. If the Strong gas be made luminous, it must, like the Lowe gas, receive a strong and characteristic odor. Herein lies, also, the only element of safety in the use of ordinary coal gas, $\frac{1}{10000}$ of which can be detected in air by its odor. Coal gas, if inodorous, would in all respects be as dangerous for domestic use as pure carbonic oxide gas.

"I have no hesitation in stating as my opinion, that 'water-gas,' either the Lowe gas or the Strong gas, when properly 'carbureted,' is in all respects as safe for household use as ordinary coal gas.

"I can not better conclude my report than by stating my entire concurrence in the opinion of the greatest living authority in chemical technology, Rudolph Wagner,* who, after alluding to the lack of success of the previous attempts to introduce water-gas, owing to imperfect apparatus, says: 'Nevertheless, water-gas still appears to us to be the illuminating gas of the future.'

"Respectfully submitted by your obedient servant,

"GIDEON E. MOORE, Ph. D.

"JERSEY CITY, JANUARY 22, 1878.

"*To the American Gas-fuel and Light Company, New York.*"

* Jahresbericht der Chemischen Technologie, 1874, p. 991.

CHAPTER XVII.

UTILIZING WASTE GASES FROM THE FURNACE.

Waste Products—Magnitude of the Loss—Siemens' Regenerative Gas-Furnace.

The waste products of furnaces may be divided into two classes:

1. The escape of gases in which combustion has been incomplete. This is confined almost exclusively to carbonic oxide, a combustible gas, formed in the furnace by a too little supply of oxygen at the time, or during the process of combustion.

2. The escape of heated products which may in themselves be incombustible, but having passed their point of application, are rendered unavailable to the purposes for which they were generated, and are thus a source of loss.

In blast furnaces, waste gases are made to serve a useful purpose in generating steam, heating the blast, etc.; in puddling furnaces, by heating a steam boiler, which is usually placed directly over the furnace; and in many other ways these waste gases are partially utilized. To show the necessity for utilization, and the magnitude of this loss in case of neglecting to do so, was clearly stated in a lecture given by Dr. Siemens, on Fuel (1873), in which he says: "Taking the specific heat of iron at .114, and the welding heat at 2,900° Fahr., it would require $.114 \times 2,900 = 331$ heat units

to heat one pound of iron. A pound of pure carbon develops 14,500 heat units, a pound of common coal, say 12,000; and, therefore, one ton of coal should bring thirty-six tons of iron up to the welding point. In an ordinary re-heating furnace, a ton of coal heats only $1\frac{1}{3}$ ton of iron, and, therefore, produces only $\frac{1}{20}$ part of the maximum theoretical effect.

"In melting one ton of steel in pots two and a-half tons of coke are consumed, and taking the melting point of steel at thirty-six hundred degrees Fahrenheit, the specific heat at .119, it takes $.119 \times 3,000 = 428$ heat units to melt a pound of steel, and taking the heat-producing power of common coke also at twelve thousand units, one ton of coke ought to be able to melt twenty-eight tons of steel. The Sheffield pot steel melting furnace, therefore, only utilizes $\frac{1}{70}$ part of the theoretical heat developed in the combustion."

These facts led Dr. Siemens as early as 1846 to consider the practicability of storing this waste heat and utilizing it again and again. In this he was successful, and his regenerative furnace marks an era in the utilization of waste gases.

Siemens' Regenerative Gas-furnace—The construction of this furnace is shown in plate IV; a description and its mode of operation are clearly set forth in the specification of his American patent given below:

"In the accompanying plate of drawings, in which corresponding parts are designated by similar letters, figure 1 is a partial longitudinal vertical section of the

furnace. Figure 2 is a horizontal longitudinal section, showing the relative position of the air and gas flues. Figure 3 is a transverse vertical section of the furnace through the cave *A*. Figure 4 is a transverse vertical section through the air flues. Figure 5 is a longitudinal elevation.

“The regenerative gas-furnace, as shown in the drawings, is built of fire-brick or other suitable refractory material, and consists of the four regenerators with the flues and valves, and the heating-chamber, where the metallurgical operations are carried on.

“The four regenerators are arranged in pairs, and vary in size, the smaller being used for the passage of gas, and the larger for that of air, their proportions being in the ratio of two to three. Approximately, these ratios correspond to the quantities of gas and air required to insure complete combustion in the heating-chamber. The walls of the regenerators are built of fire-brick or other suitable refractory material, closely laid and white-washed, or otherwise made gas-tight, so that no leakage may take place from one chamber to another. These chambers are filled with refractory material, by preference fire-brick, stacked loosely together, and each regenerative chamber has its own separate flue at the base, communicating with the valves by which the gas and air enter, or the products of combustion pass out, while from the top or side of each regenerative chamber a series of flues pass upward and communicate with the

heating chamber; and I prefer to cause the air to enter the heating chamber above the gas, as by its superior specific gravity at equal temperatures it tends to sink through the gas, and thus an intimate mixture and more perfect combustion is obtained. The entering or issuing gaseous currents pass through valves, which are shown in *x* in figure 3.

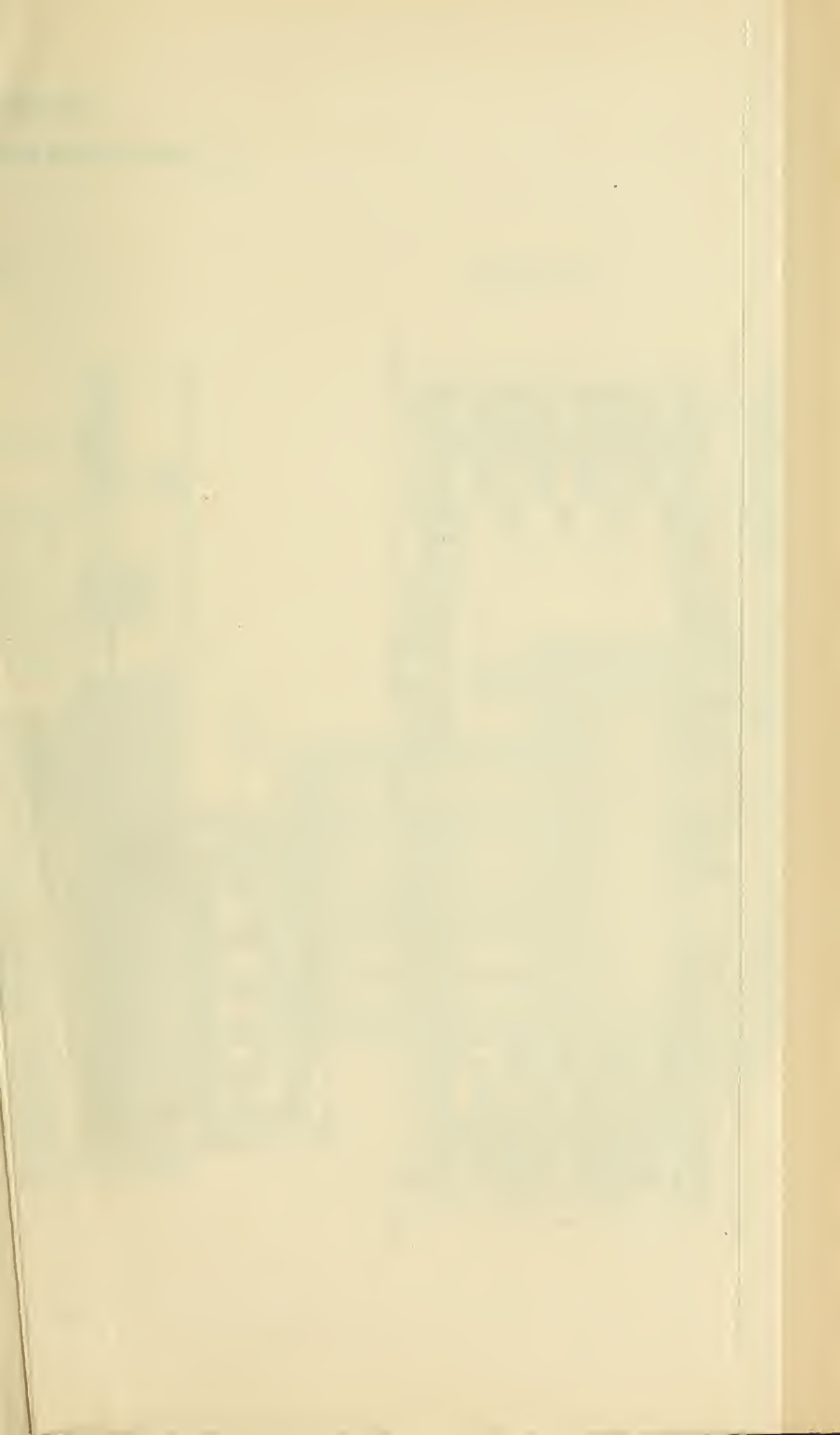
“The heating chamber where the metallurgical processes are carried on, has its roofs and sides constructed of highly refractory materials, such as best silica or Dynas bricks. The bed is usually made of sand.

“Below the center of the furnace is an open cave, *A*, through which air freely circulates, and rises through openings into the air-space below the melting chamber and behind the bridges, whereby a perfect cooling of the sides of the melting chamber is effected. This cave serves, moreover, as a receptacle for any metal which may break through the sides or bottom of the melting chamber, whence it can be removed at leisure, without, meanwhile, encumbering the ventilating spaces around the melting chamber.

“On first lighting the furnace, the gas passes through the proper valves and flues into the bottom of regenerator chamber *c*, while the air enters through corresponding valves and flues into the regenerator chamber *E*, which should be about one-half larger than the gas regenerator chamber *c*. The currents of gas and air, both quite cold, rise separately through the regenerators *c* and *E*, and pass up through the series of flues *G G G G G* and *F F F F F*, respectively, into

the furnace above, where they meet and are lighted, burning and producing a moderate heat. Each air-port rises from its regenerator behind the corresponding gas-port, and is projected into the furnace over such gas-port, it being important that the air-port should overlap the gas-port on both sides. Great solidity of brick work and perfect combustion is thereby attained.

“The products of combustion pass away through a similar set of flues at the other end of the furnace, into the regenerator chambers $c' E'$, which are not shown in the drawings, but are symmetrical, both in construction and arrangement, with the chambers $c E$, already described. The products pass from thence, through properly-constructed flues and valves, to the chimney-flue. The waste heat is thus deposited in the upper courses of open fire-brick work, filling the chambers $c' E'$, and heats them up, while the lower portion and the chimney-flues are quite cool; then, after a suitable interval, the reversing flaps—through which the air and gas are admitted or withdrawn from the furnace—are reversed, and the air and gas enter through those regenerator chambers $E' c'$, which have been just heated by the waste products of combustion, and in passing up through the checker-work they become heated, and then, on meeting and entering into combustion in the furnace D , they produce a very high temperature, the waste heat from such higher temperature of combustion heating up the previously cold regenerators $c E$, to a corresponding higher heat. Thus an accumulation of heat and an accession of temperature is obtained step



C.W. SIEMENS.
REGENERATIVE GAS FURNACES.

FIG. 1.

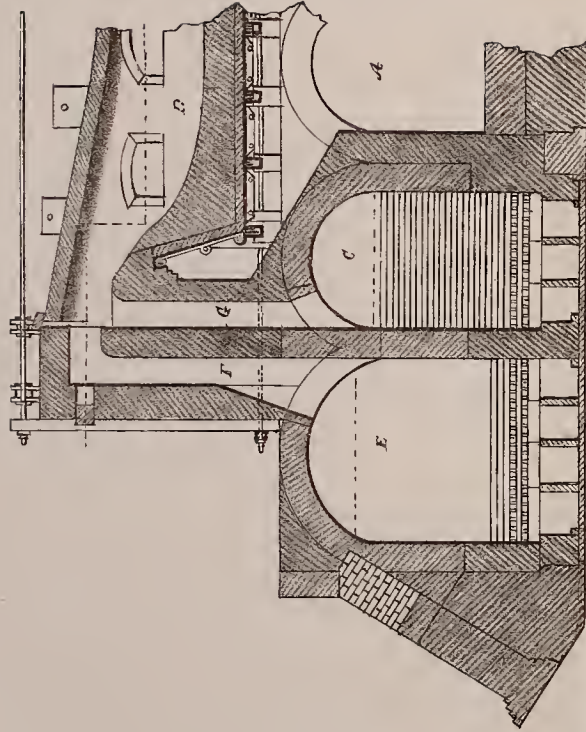


FIG. 2.

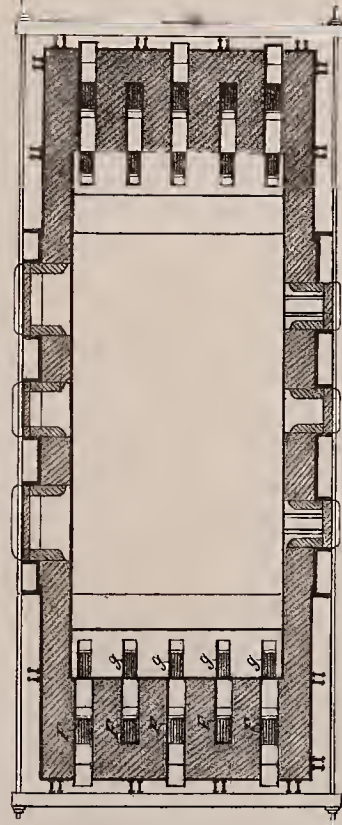


FIG. 3.

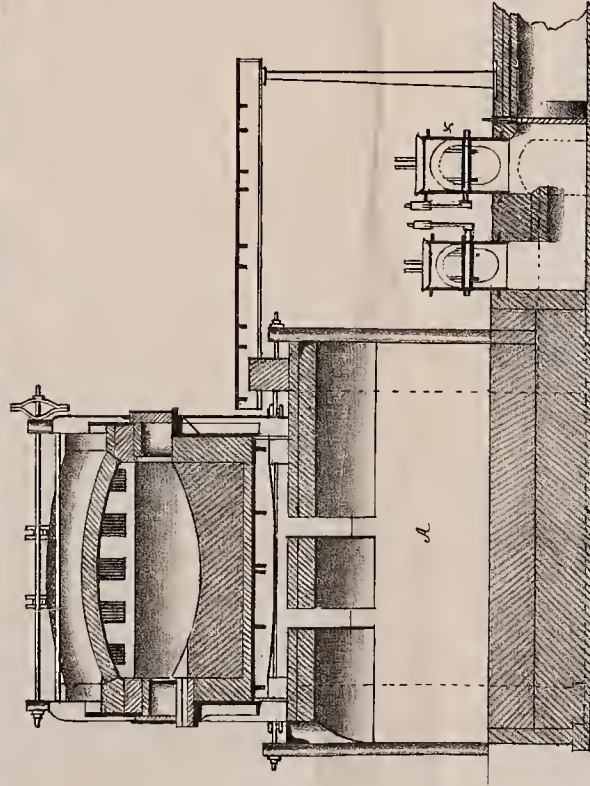


FIG. 4.

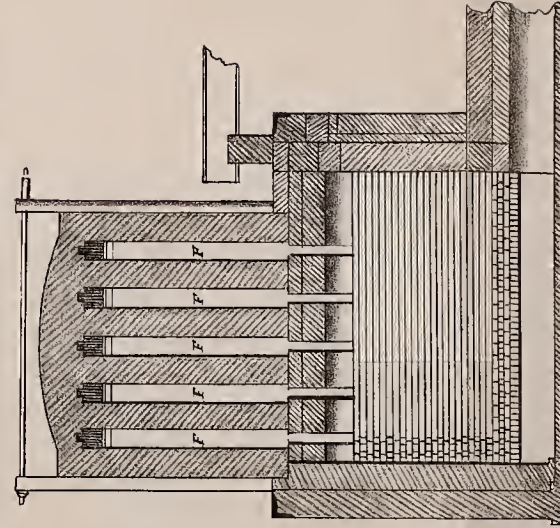
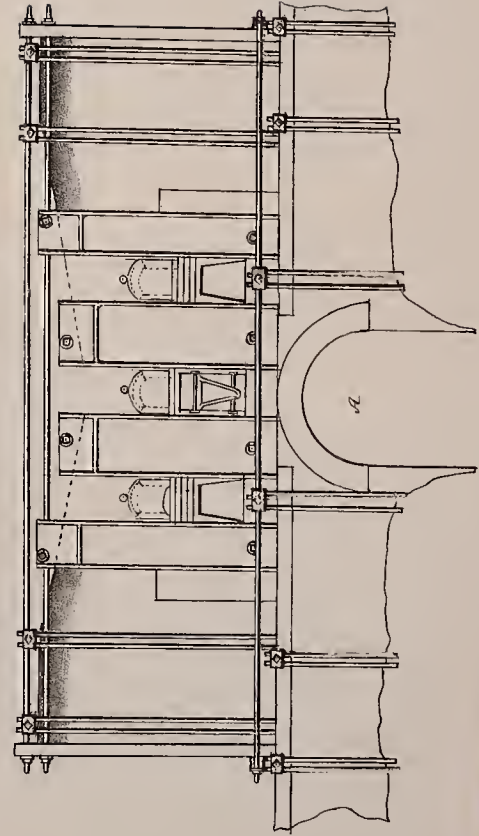


FIG. 5.



by step, so to speak, until the furnace is as hot as required. The heat is, at the same time, so thoroughly abstracted from the products of combustion by the regenerators, that the chimney-flue remains comparatively cool.

“The command of the temperature of the furnace, and of the quality of the flame, is rendered complete by means of gas and air-regulating valves, and by the chimney damper.”

CHAPTER XVIII.

A. PONSARD'S PROCESS AND APPARATUS FOR GENERATING GASEOUS FUEL.

The following is a copy of the specifications of Auguste Ponsard, Paris, France, describing in detail his process and apparatus for generating gaseous fuel:

“It is the object of my invention to increase the production of carbonic oxide from a given quantity of fuel; to produce this gas at the highest possible temperature, so as (without passing it through any cooler or regenerator) to introduce it at the highest possible temperature to the furnace in which it is to be consumed; to support the combustion of this gas by the introduction to the furnace of air previously heated by the waste products of combustion, and to simplify the apparatus required for the production and consumption of gaseous fuel, while attaining a higher heat than has been heretofore obtained therefrom.

“Previous to my invention, when the highest heats from gaseous fuel have been required it has been necessary that the temperature of the gas should be raised before its introduction to the furnace for combustion, not only because it could not be produced at a sufficiently high temperature, but because much of its original heat had been lost in its passage from the producer to the furnace, in most instances widely separated. In that system the expense of the apparatus is increased,

not only by the cost of the separate structures, but by the means required to connect them; and as the more volatile particles of the gas are deposited in passing from the producer toward the furnace, and in restoring the heat by the recuperator the gas deposits another portion upon the recuperator, this operation is attended with a constant waste of fuel.

“My invention consists, first, in supporting the combustion of the gas-producing fuel by supplying it with a continuous current of highly-heated air, and so regulating this supply as to control the activity of the combustion; second, in defining the traverse of this air, and the gas produced thereby, so that the gas shall pass off at the highest temperature; and, third, in effecting an intense combustion by the introduction to this gas, as it passes to the furnace, of air previously heated by the waste products of combustion.

“At the ordinary temperature of the atmosphere, the air and the fuel for the production of carbonic-oxide gas will not combine with sufficient rapidity to produce sensible heat. The rapidity of their combination and the intensity of the resultant heat are probably in proportion to the temperature of the two, respectively, previously to their combination.

“In gas-producers, as heretofore constructed, the gas-producing fuel performs two functions—first, to heat the air and the fuel to a sufficient temperature to continue an active combustion, producing carbonic-acid gas, and, second, to heat the remaining fuel to such a degree that a slower combustion without flame will take place,

in which the carbonic acid should take up another charge of carbon and become carbonic oxide; but in all such producers a portion of the carbonic acid will pass through without taking up another charge of carbon.

“Now, if the air which is to support the primary combustion should be so heated that none of the heat from the fuel would be required for the primary conditions, the carbonic acid would be produced at a much higher temperature, and its liability to pass through the remaining fuel without taking up another charge of carbon would be diminished, so that the product of carbonic oxide from a given quantity of fuel would be greater than has heretofore been obtained. Moreover, the air coming to the fuel heated, instead of to be heated, not only promotes the combustion of the fuel and the production of carbonic oxide, but it also intensifies the temperature of this gas by the direct contribution of heat instead of abstracting it, as heretofore.

“It must be borne in mind that the consumption of fuel at any temperature, however high, will be proportioned to the quantity of air admitted to combine with it, so that, while the quantity of air admitted is kept within the limits which must be observed to prevent a too active combustion, the result obtained will be an increased quantity of carbonic oxide at a higher temperature than has heretofore been possible.

“In the accompanying drawings I have shown an improved apparatus, in which the operation of my invention is exemplified.

"Figure 1 represents a vertical longitudinal section of my improved apparatus applied to a heating-furnace, line of section *A B*, figure 2. Figure 2 is a horizontal section thereof, following the line *C D*, figure 1. Figure 3 is a vertical transverse section on the line *a b*, figure 1. Figure 4 is a vertical transverse section on the line *I J*, figure 1. Figure 5 is a vertical transverse section on the line *e d*, figure 1. Figure 6 represents in detail, and upon an enlarged scale, the hollow bricks which I use, and the manner in which they are put together in the recuperator. The principal feature in their construction is the recessed ends *s*, which, when in position, as at *s' s'*, form chambers in which fire-clay can be packed, so as to form a key to hold the structure together, as well as an interruption to the passage of gas and air at the joint. This general arrangement of the recuperator is the same as described in letters patent of the United States No. 130,313, granted to me August 6, 1872.

"The gas-producer consists of a rectangular chamber, *a*, the lower part, *b*, of which is greatly contracted, in order that the residuum of the fuel (cinders and slag) in the contracted space, *b*, may be easily removed with stoking-irons.

"The fuel is charged through the hopper and clap-valve *c*, and the arch *d* serves to limit its height in chamber *a*. The fuel is supported by the hearth *p*, upon which the cinders and slag will accumulate, and from which they may be removed, as hereinafter described. The hot air is brought from the recuperator

i to the front of the producer through the conduit *e*, and reaches the fuel through the opening *f*, which takes up nearly the whole width of the chamber *a*.

“The ash-pit *g* can be closed by means of vertically-sliding doors of sheet-iron, *h*, which are raised by means of counter-weights; or it may remain open if the pressure of the hot air entering the producer is not great enough to force back the gas through this part of the apparatus. To prevent the loss of gas which might result from its driving back under pressure, the sliding doors may, after each clearing of the pit, be luted with ashes, earth or sand.

“In the front wall of the contracted portion *b* of the producer, above the arch of the ash-pit, openings *j* are provided, through which stoking-irons may be introduced to lift and stir the fuel; and to remove the ashes and slag to the lower part of the apparatus through the openings *j*, bars may be inserted to sustain the fuel above the hearth, and within the producer, while the ashes, cinders or slag are being removed from the hearth *p* beneath the bars. In the side walls of the producer are also provided openings *k*, which, together with the sight-holes *l*, arranged in the arch, allow the introduction of stoking-irons to compact the fuel, and to break up any arches that may be formed by the agglomeration of coal, especially if a rich kind of coal is used. The recuperator *i* is divided into two parts, one of which serves to heat the air required to support combustion in the producer, and the other to heat the air for the combustion of the gas as it enters the fur-

nace by means of the passage *m*. This division of the recuperator into two distinct parts may be made complete or partial only; in other words, they may be entirely separated by a solid wall, or the transverse air-passages only may be filled up (divided) by solid bricks, leaving the passages for products of combustion in communication. This latter disposition is represented in the drawing.

“Whatever arrangement may be adopted, independent valves must be placed before each group of orifices for the admission of air into the divided recuperator, to regulate the quantity of air admitted to the producer, as well as to the furnace. In the drawings, the position of these valves is represented at *n*, figure 1, in the rear of the recuperator, and they are operated by screwed rods *n'* and hand-wheels *o*.

“With a view to obtain the maximum advantages of my improved system hereinbefore described, I contemplate varying, under varying circumstances, the construction of the producer, with the view, in all cases, to admit the air above the hearth, to define its traverse through the fuel, and to carry off the carbonic oxide from that section of the producer where this gas is the hottest.

“In the disposition represented in figures 7 and 8, the gas-producer consists of a vertical chamber, *a* (which is charged with fuel by means of two ordinary valve-boxes, *b'*), the lower portion of which presents openings upon opposite sides, by means of which the cinder and ashes may be removed. To this end the lower portion of the

space *a* terminates in two inclined planes, *c*, extending down to a certain distance above the ground, in such manner that raking-bars may be easily inserted into the openings thus provided, to remove and loosen the ashes and cinders accumulating in this portion of the producer. In this disposition the conduit *b* for the out-going gas is placed lower than shown in the drawings, figures 1 to 5, and is elevated above the plane of the conduit *c*, for the admission of air, so that the air will traverse the fuel in a slightly-ascending plane.

“Figures 9 and 10 represent a gas-producer, *a*, which from the top to its base presents the form of a frustum of a pyramid. This is varied in width according to the nature of the combustible employed. In this disposition the conduit *b* of the out-going gas is placed at the same height with, or even a little lower than, the conduit *c*, supplying the hot air, and the two orifices of these conduits are fitted with a grating, *d*, forming a part of the inclosure of the space *a*. This grating is constructed of refractory pieces (as bricks), the shape of which may vary, while they are so disposed as to leave sufficient sectional area for the air and gas. These bricks are simply built up without the interposition of any mortar, so that they may be easily replaced (when deteriorated) through the openings *e*, provided in the two parallel long sides of the producer. The lower part of the apparatus is closed by loose walls *f*, which are withdrawn to remove the ashes produced by combustion, the coal remaining supported during this time by the grate *g*,

the removal of a few bars of which will allow the cinders accumulated in this part of the producer to fall.

"Figures 11 and 12 represent diverse arrangements of the gratings *d*, designed to prevent the coal from falling out laterally into the passages *b* and *c*, for the outlet of gas and inlet of air. In figure 11 the grating is formed by thin bricks *h*, laid flat upon bearers *i*, leaving passages between these shallow enough to prevent the coal from sliding outward. In figure 12 the grating is formed of hollow bricks *j*, arranged in quincunx, or simply superposed, so as to leave numerous passages for the gas and air, while they prevent the coal from obstructing the passages *b* and *c*.

"It is evident that the forms and dispositions of these pieces of refractory clay may be greatly varied without inconvenience, provided they are arranged to be easily withdrawn and replaced through the openings *e*, when they become injured from use.

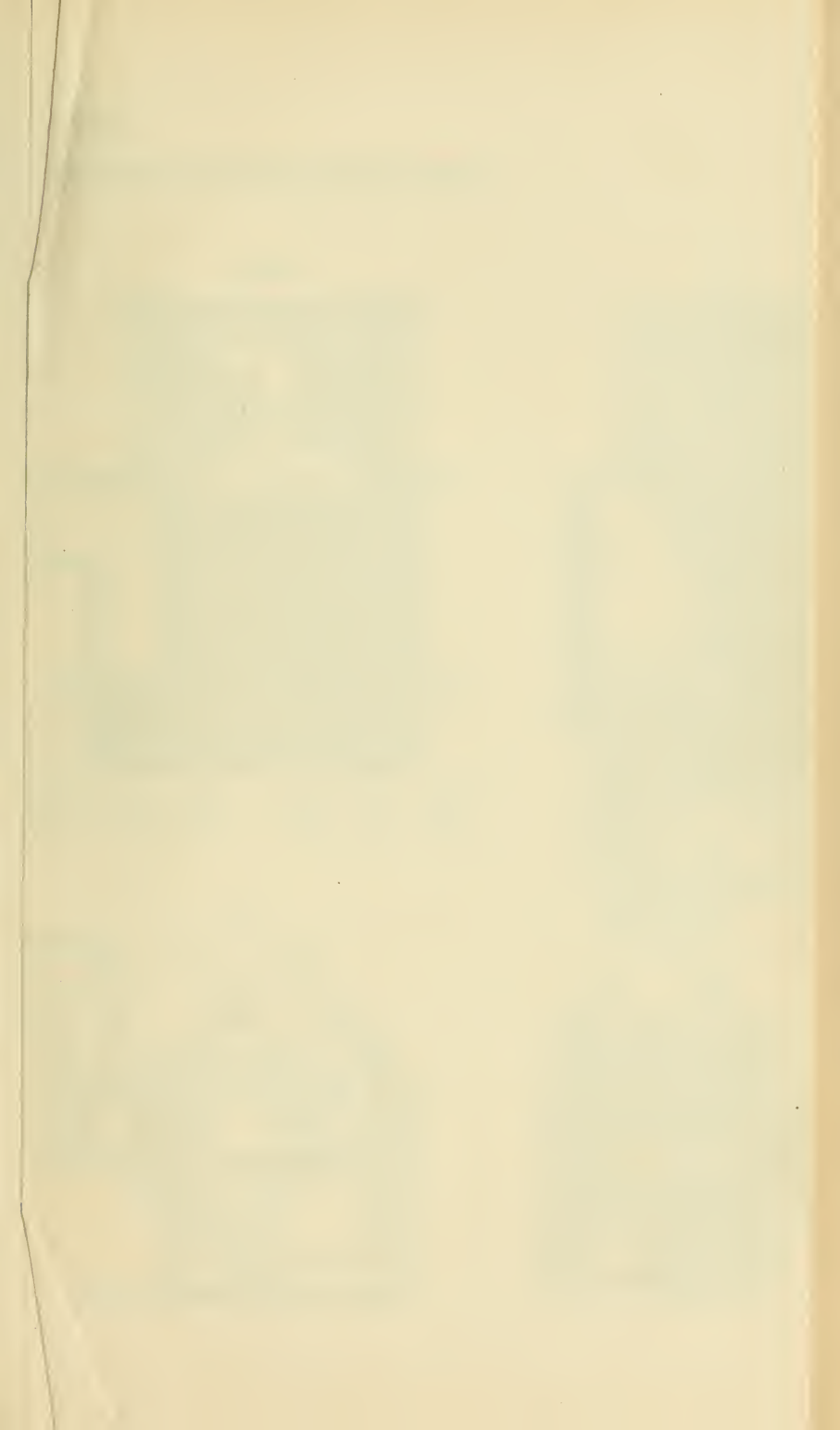
"Figures 13 and 14 represent a producer in which only the orifice *b* for the outlet of gas is closed by a grating, *d*, disposed in steps. The other side where the air is admitted is inclined, and if a similar inclination is given to the grating, the layer of coal traversed by the air is about equal at all points.

"Figures 15 and 16 represent a producer, in which the hot air enters the fuel from above, and the gas may go out through one side or both sides of the apparatus. The drawing represents two outlets, *b*, and I have also increased the width of this part of the chamber, so that the layer of fuel traversed by the air may be

as uniform as possible. It will also be observed that I have provided in the masonry offsets, *k*, into which the fuel may slide, and which will tend to prevent the hot air entering by the passage *c* from following the inclosure of space *a*, and compel it to traverse the fuel before reaching the outlets *b* for the gas.

“The air which supports combustion in the gas-producer acquires the force necessary to enter the producer from the heat which it receives in passing through the recuperator; but it may also be injected either by means of a blower, or by a jet of steam, or by a blast-engine of any kind. Of these methods I prefer to employ the jet of steam, because the steam in passing through the fuel is decomposed, and produces a gas rich in carbon. I obtain this result, when the air is not forced, by admitting into the lower part of the recuperator a small quantity of water by means of an iron tube which is inserted into the air-inlet, as shown in figure 1. This water is vaporized in the iron tube, and escapes as steam into the recuperator.

“I am aware that a gas-producer has been described, in the operation of which previously-heated air was introduced to support the combustion of the gas-producing fuel. Two regenerators and conduits alternately carried a current of air to, and a current of gas from, the producer, and these currents were reversed for the purpose of heating the air, but with the effect of cooling the gas. Each conduit and regenerator, therefore, was alternately filled with gas or with air, so that with each reversal of the currents, the gas contained in the



PROCESS & APPARATUS FOR GENERATING GASEOUS FUEL.

[illegible]

The first system of musical notation for 'The Bird Song' consists of two staves. The upper staff begins with a treble clef and a key signature of one sharp (F#). It contains a half note G4, a quarter note A4, and a quarter note B4. The lower staff begins with a bass clef and contains a half note G3, a quarter note A3, and a quarter note B3. The word 'h' is written above the first measure of the upper staff, and 't' is written below the first measure of the lower staff.

one was returned through the fuel, while the air contained in the other was delivered into the flue leading to the furnace, where it would mix with and deteriorate the quality of the gas. In this case the length of the flue to the furnace permitted an admixture; but with a delivery directly into the furnace, such as I contemplate and set forth, the flame would be extinguished, and its place supplied by a blast of heated air alone at each alternation, which would not only diminish the heat, but oxidize the contents of the furnace."

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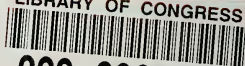
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